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SITE CHARACTERIZATION OF HILLSLOPES IN RIBEIRÃO CONTAGEN FLUVIAL VALLEY (BRASILIA, BRAZIL) USING GEOPHYSICAL METHODS

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Abstract

The properties of vadose zone material are highly important in the analysis of landslides as well as for various hydrogeological studies and engineering applications which can prove effective in an emergency situation and help in damage evaluation. The present study applied a joint analysis of Multi Channel Analysis of Surface Waves (MASW) and Electrical Resistivity Tomography (ERT) for the subsurface characterization of a landslide. In MASW subsurface shear wave velocity is obtained by the inversion of Rayleigh wave dispersion curve (phase velocity vs frequency) while ERT makes use of the geoelectrical information of the substratum and the best fit model between the observed and measured values provide the subsurface stratigraphy. Data acquisitions at a landslide in a small Ribeirão Contagen fluvial valley was done using 14 Hz geophones and 2D resistivity profiles using dipole-dipole array configuration. Resultant slip surface and permeable paths were identified well on the modeled resistivity sections, while a three layered 2D shear wave velocity stratigraphic section is obtained from MASW where a continuous increasing rigidity trend and a decrease in velocity at landslide scarp are observed. In future borehole data along long length MASW profiles are recommended for the detailed investigation.

Introduction

In geotechnical investigation usually, stiffness and permeability of the in situ soil are analyzed. The measurements of which are critical in the case of safety of civil engineering structures (buildings, tunnels, excavations) and natural hazards such as landslides. The stiffness of soil can be calculated by both in situ and laboratory tests including resonant column test, ultrasonic pulse test, cyclic simple shear test, cyclic triaxle compression test, and cyclic torsional simple shear test. There are limitations associated with the laboratory tests such as sampling disturbance and to unrepresentative sampling in order to overcome field techniques are rapidly adopted (Singh et al., 2017).

In comparison to these geotechnical techniques, the geophysical methods, especially, MASW and ERT have appeared as cheaper, noninvasive and time saving alternative (Taipodia et al., 2018). In electrical resistivity method a known amount of electrical current is injected into ground by using an electrical apparatus (two current (source and sink) and two potential electrodes) each material provide its own specific range of resistivity (dry and water bearing sediments, differing rock lithologies differing weathering histories and degree of material deformation). These resistivity values are measured at each point with homogeneously varying electrode spacing. The flux of electric current goes deeper with

increase the electrode spread i.e for short distance the near surface material is observed while with larger separation greater depth is investigated. This flux will be crowded in the conductive material while it is rarefy in the resistive layers. Resultant potential difference variations are measured through which electrical resistivity profile of the subsurface is constructed.

The present work was carried out for the understanding of structural differentiation and the geology of the landslide medium by a combined use of MASW and ERT methods. Here the surface waves are generated over various locations in the study area (an active fluvial channel valley). The inversion of surface wave dispersion curve is used for the subsurface site characterization. Along with MASW, the electrical resistivity measurements using dipole-dipole configuration were also carried out for the landslide site characterization by using their geoelectrical properties. The attempts have also been made for the determination of slip surface of the landslide that can be used for its volume estimation.

Study Area

The Ribeirão Contagem watershed is 146 km² extended and it is located in the northern part of the Federal District of Brazil in the Sobradinho administrative unit. The Maranhão River, is the main tributary of the watershed that flows in the north-northeast directions. The drainage and channel densities of the watershed are 5.7 km/km² and 32.9 channels/km². The climate in the area is semi-humid tropical with a rainy summer and dry winter. The mean annual precipitation in the area is of 1,442.5 mm and it is mainly related to rainfalls. The study area has been extensively studied using geophysical (Hussain et al. 2017a; 2017b; 2018; 2019) and geomorphological analysis (Braga et al. 2018).



Figure 1. Figure 1 (A) Map of Brazil, (B) position of Ribeirão Contagem watershed on Federal District, (C) The locations MASW (L1) and ERT-1 profiles

The slope chosen for this study is located in the Federal District of Brazil near a cow and horse ranch in a small vicinity named 'Rua do Matto'. This landslide is an E-W trending rotational earth-slide. The landslide mass is approximately 150 m long and about 70 m wide. Along with the main scarp at the top, there is a scarp in the middle, created by a 2 m height normal fault originated by the release effect of the Contagem River that eroded the landslide body. The erosional potential of this river is related to rainfall in the surrounding areas, which is quite high during rainy season.

Data and Methods

Electrical Resistivity Tomography

The ERT method is based on injecting a known amount of current to the ground by two metal electrodes called current electrodes. The amount of current encounter resistance from the subsurface soil conditions (degree of fractures, material types and degree of saturation) and a potential is developed which is measured by two other metal electrodes know as potential electrodes. The method is affected by the geometry of deployment of these four electrodes on the surface and hence the technique can be used in three basic ways: 1) vertical electrical sounding (VES) 2) profiling and; 3) electrical tomography where a large number of electrodes and combinations of electrode pairs are used. VES is quick and results are easy to process and interpret. However, it is limited to vertical resistivity variation (1-D assumption) and long acquisition profiles are required in order to reach greater depths. Another drawback of method is its data explanation by infinite solution (non uniqueness problem). While in the case of the occurrence of landslide in an area there are lateral and vertical variations, under these conditions the application of VES become questionable. However, the resistivity tomographic techniques that provide 2D and 3D image of area are adopted as standard geophysical imaging techniques.

Multi-channel Analysis f Surface Waves

The surface waves are dispersive means different frequencies behave differently while passing through a layered subsurface each constitutes a distinct impedance contrasts. This property of surface wave is used for the subsurface site characterization (such as stratigraphy, shear velocity, and depth to bedrock). There are different methods that utilize this characteristic of the surface waves. However, the MASW is proved advantageous over other geophysical methods in the determination of soil stiffness, especially in a case where subsurface characterization is required over undisturbed conditions and coarse grain material like gravels, as is the case with landslide site. Here, shear wave disturbances in the soil rotational and dilatational strains can be determined which are used for site characterization after inversion.

Survey planning for the MASW and ERT are done using Google earth. The data were acquired along three profiles in the study area in such orientations so the projected area can be covered (Figure 1). The 48 channel Geode (Geometrics Inc.) seismograph along with 14 Hz geophones were used for the data acquisition. The seismic source used was a hammer with 8 kg, struck against a metal plate placed on the ground. Energy generation at each point was repeated (5 and 15) times and stacked in this way the signal to noise ratio was improved. The profile L1 along with ERT-1 run perpendicular the landslide and their small portion touches the landslide scarp at the top (Figure 1). The generalized working principles of MASW and ERT are shown in Figure 2.

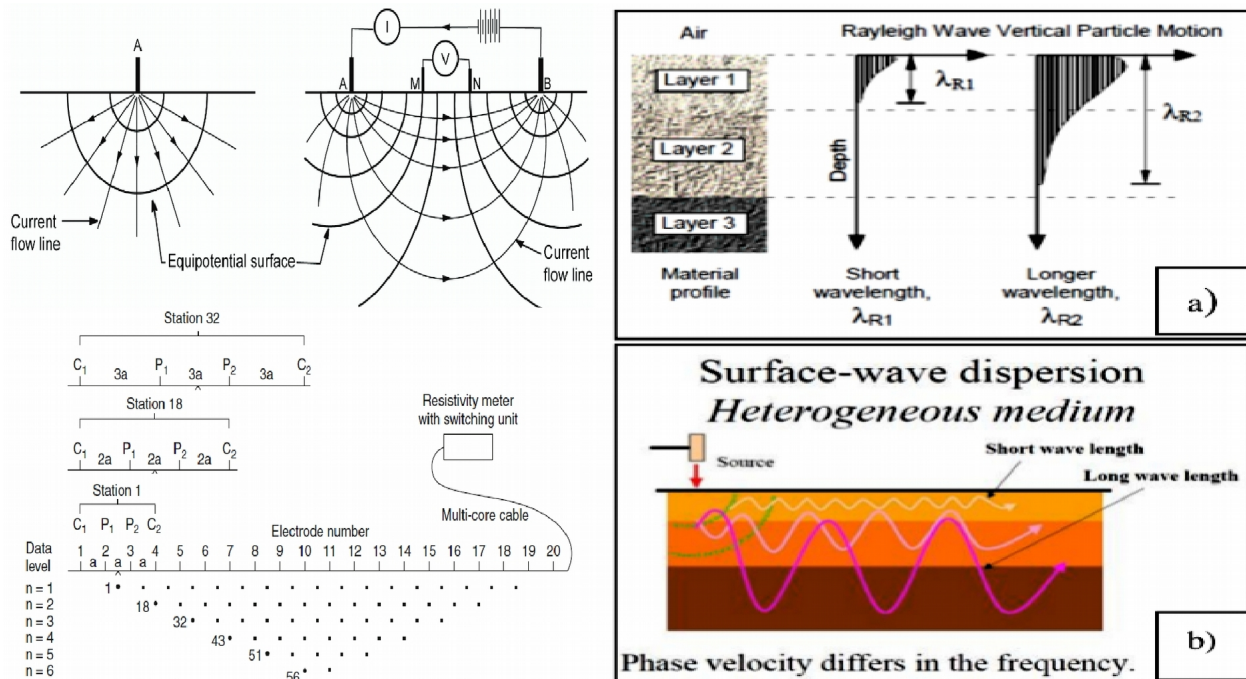


Figure 2. a) Different wavelengths penetration depth, b) Different wavelengths propagation (Moura et al., 2015) and (left) a) an electrical resistivity working principle and b) dipole-dipole array are shown

Discussion and Conclusions

Results are plotted as apparent resistivity values at the top, best fit model in the middle and inverted resistivity (true resistivity) at the bottom. An apparent resistivity section is calculated from software and is compared with field apparent resistivity values. Then by comparison of these to apparent resistivity value at a RMS error of 3.8 % the best fit resistivity model of substratum is obtained (Figure 3). At the beginning of the profile above landslide scarp, low resistivity values are found that are related with disturbed material because of the presence of landslide which is also evident from the MASW analysis. As we move away from the landslide scarp over undisturbed material, different resistivity values are observed (Figure 3).

The fundamental and first higher mode (bimodal propagation) of Rayleigh waves are observed over the dispersion curves calculated over the profiles (L1). However, only fundamental mode of dispersion curve is used in the inversion due to initial model can't be well constrained from Figure 2. It is also evident from the Figure 4 that after a certain frequency value, the phase velocity decreases with increase in frequency. White dots show the phase velocities interpreted at selected frequencies for the fundamental (used in the inversion).and first higher modes.

The inversion results are presented on 2D plots as contours of shear wave velocity (Figure 4). Results presented here have demonstrated that the site has three layers over a homogeneous half space. which suggests a join yellow to reddish clay, after joint Clay and Saprolite clayed, so transitional contact

is the semiespace. The densities are 1.2, 1.6 and 2 kg/cm³. The inversion starts with 300 m/s and ends at 700 m/s.

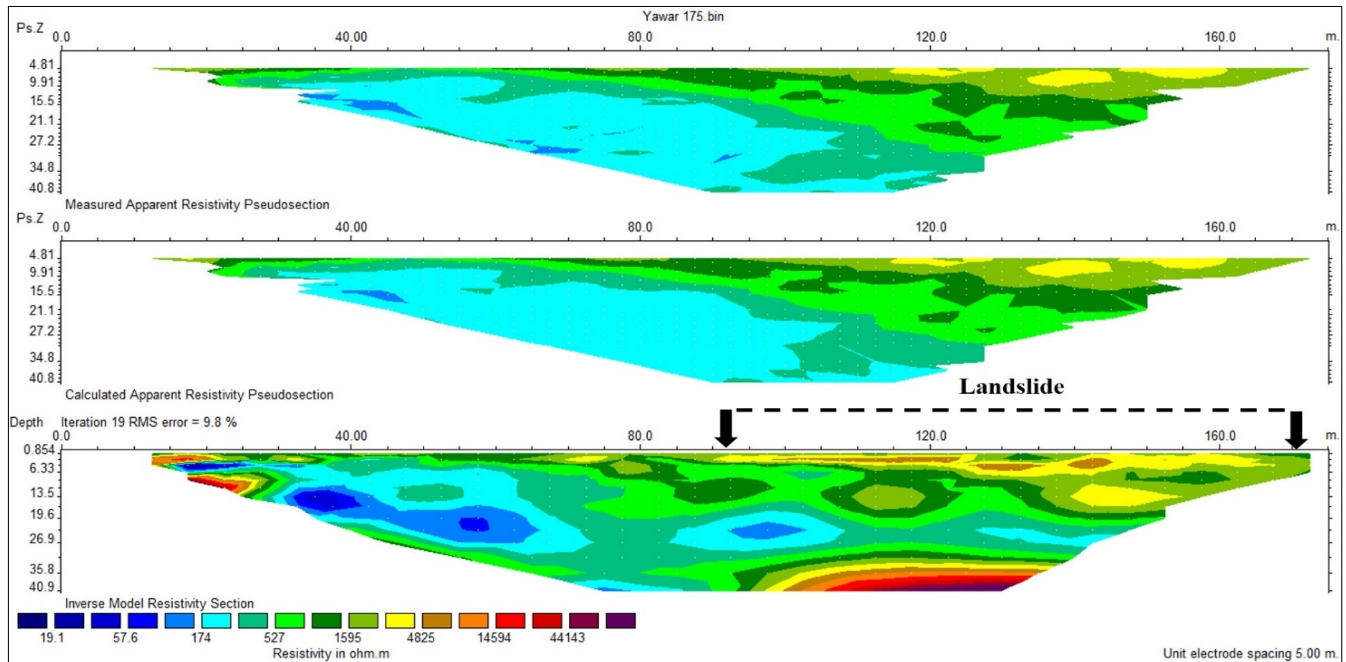


Figure 3. Inversion results of electrical resistivity tomography at Sobradinho landslide. The black dotted line shows landslide area.

At profile L1 that run parallel with the landslide body, following surface velocity layers are delineated on 2D shear wave velocity section with VS values as 160 to 440 m/sec, 330 to 540 m/sec and 440 to 660 m/sec, respectively. The persistent depth dependent rise in the VS is maintained here, however between distances 42 to 56, the region where profile passes through landslide scarp (crest), greater disturbance in subsurface layers are observed which may possibly be linked with the material deformation created by the onset of the landslide in the past.

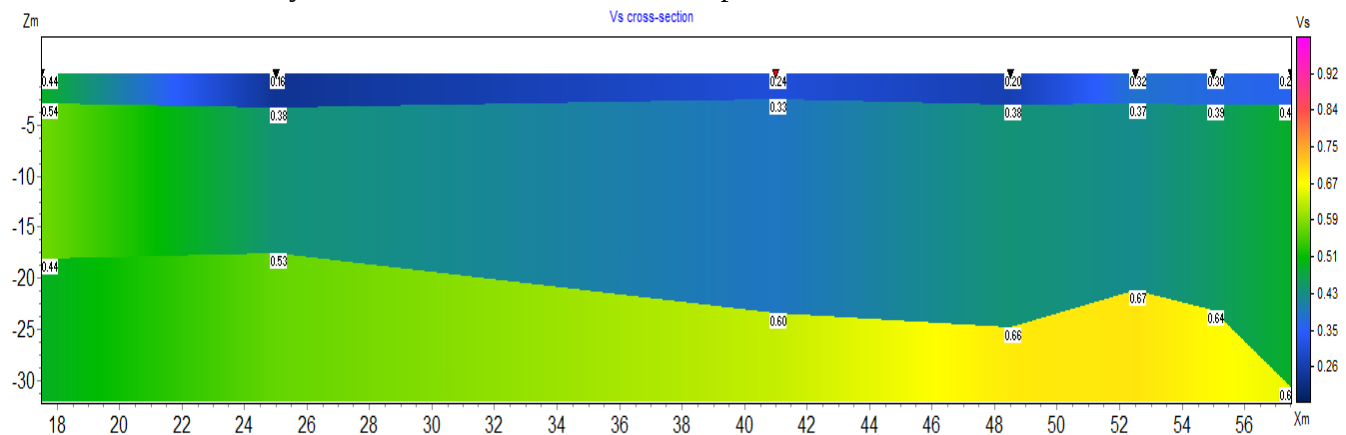


Figure 4 Results of MASW a 2 D shear wave velocity profile of the area. Color bars are the VS velocities in km/sec.

Conclusions

A joint MASW and ERT field approach was carried out for the characterization and for the delineation of slip surface of landslide in the morphologically active fluvial valley in the federal district of Brazil. Following conclusions are drawn from the analysis. Landslide slip surface was found at 8 m depth on resistivity profiles however it was not possible to delineate landslide slip surface using MASW results. The low signal to noise ratio of the seismic record at some of MASW records made the interpretation dubious. There are small discontinuities filled with resistivity materials are over the horizontal and transverse directions of landslide body that are possibly linked with rainfall infiltration and a source of pore water pressure which may lead to reactivation of landslide at slip surface in the case of extreme rainfall movement. However, future detailed studies are recommended for the confirmation of the aforementioned results.

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