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Forward and inverse modeling of electrical resistivity geophysical data of a landslide surface discretized by unstructured mesh - A case study: Tehran-North Freeway

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Extended Abstract

Summary

Geoelectrical surveys are commonly used to image the subsurface and provide valuable information about the electrical properties of targets in the subsurface. In this study, we focused on investigating areas with rough topography and complex-shaped electrical structures using unstructured meshing. Electrical resistivity tomography (ERT) was employed as a common method for near-surface geophysical investigations, allowing us to determine different earth layers based on their electrical properties, and also, to identify potential landslide-prone areas. To solve the geoelectrical problems, we utilized a program called ResIPy, which employed a triangular mesh based on finite element algorithm. By simulating an artificial landslide, we found that the triangular mesh provided more accurate identification of geological formations compared to a structural mesh with rectangular elements. Additionally, the algorithm execution time with the new mesh was reduced, requiring less memory. We then analyzed the field data from a landslide-prone area located approximately 10 kilometers northwest of Tehran Province. The data were collected from 31 stations along four ERT survey lines with a separation distance of 20 meters over the landslide surface. The surface in this area is characterized by low electrical resistivity property and is composed of heterogeneous materials such as alluvium and tuff, making it very slippery. We identified three distinct subsurface layers with significant differences in electrical resistivity. The surface layer consists of heterogeneous materials with electrical resistivity ranging from 30 to 100 Ohm-m, and in some regions, up to 200 Ohm-m, indicating crushed areas of alluvium and tuff. This layer is observed up to the depth of 15 to 20 meters in electrical cross-sections. The second layer with a resistivity below 40 Ohm-m is identified as an alluvial and conglomerate layer. At greater depths, we found a layer composed of high resistivity Alborz tuff.

Introduction

Mass movement, which refers to the displacement of materials near the surface and in shallow areas, poses a significant threat in regions with rugged topography. This natural hazard can cause irreversible damage to various engineering structures, water sources, and vegetation. To accurately identify and comprehend this hazard along the Tehran-North Freeway, we have employed the geophysical technique known as electrical resistivity tomography (ERT). By utilizing the Schlumberger array for the electrical surveys, the apparent resistivity data were collected from the landslide surface, and were then modeled using both structural and unstructured meshes in ResIPy computer program. This particular electrical array demonstrates a heightened sensitivity, making it more effective in accurately delineating the boundaries of the topography in rough terrains.

Methodology and Approaches

In order to assess the effectiveness of the geoelectrical method in modeling landslide surfaces, a synthetic three-layer model was created to mimic the electrical properties observed in a real landslide near Tehran-North Freeway. This three-layer sloping model was designed to closely resemble the field observations. The forward modeling process was carried out using R2 code that is an open source software utilizing finite element mesh. The R2 code automatically generates simple structural meshes and allows for the use of both structured and unstructured meshes. In this case, triangular cells with vertical and lateral elongation were used to create an unstructured mesh. It is worth noting that when structured cell-based methods are employed to generate a mesh with quadrilateral shapes, the vertical length of the cells increases with the depth of the modeling domain, while the lateral lengths remain constant. This can result in an increase in model parameters, and subsequently, can lead to longer modeling time. Additionally, the structured mesh may not be as suitable for targets with irregular geometry or surfaces having rough topography, as it can introduce some errors in the electrical resistivity model obtained from the inverse modeling process. Furthermore, the use of structured mesh generally requires more computer memory and longer processing time compared to triangular mesh. However, in the case of the synthetic scenario, both the structured and unstructured meshes were able to accurately recover the electrical model, with the predicted data closely matching the actual observed values. The same approach was then applied to model real data collected along the Tehran-North Freeway, with the aim of identifying a potential landslide-prone zone.

Results and Conclusions

The objective of this research was to examine the likelihood of a landslide occurring in the Tehran-North Freeway by utilizing geophysical modeling of electrical resistivity data. We employed the finite element method to achieve this goal. Typically, modeling algorithms based on finite element method, are more intricate but yield more accurate results compared to finite difference method. To address this complexity, we utilized an unstructured mesh, which allowed for efficient and precise modeling. In this study, the performance of both quadrilateral and triangular algorithms for two-dimensional inversion was investigated on both synthetic landslide scenario and real field data collected from a geoelectrical survey conducted in an area with rugged topography. The findings indicated that the unstructured mesh outperformed the structured mesh in terms of accuracy in recovering the landslide model and computational time required for the inverse modeling. Ultimately, the study demonstrated that the geoelectrical approach is well-suited for landslide investigation and enables the mapping of landslide surfaces. Consequently, it is highly recommended to combine the method used in this study with other applicable methods to effectively monitor landslides and provide early warnings to prevent potential damage to infrastructure and human lives.