Evaluating the Geological Structure of Landslides through Hydrogeological Modeling of Subsurface Sections, Using an Integrated Geophysical Approach

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Abstract

The combination of different geophysical techniques is necessary for the learning of different seismic hazard complications, like subsurface cavities, sinkholes, internal erosion and even seismotectonic zoning. A multidisciplinary approach based on the integration of satellite, GIS techniques, applied geophysical techniques and hydrogeological evaluation can be used to investigate such problems for the large area. Similarly, commonly used qualitative geotechnical logging methods, including TCR, SCR, RQD, limited GSI and RMR techniques can be used to identify unseen potential hazards or quantify significant changes in rock mass quality, such the minimal effort can identify significant weak zones. In this research, geophysical 3D-ERT will be performed to measure the hydrogeology by electrical resistivity along different profile across the area and calculating the parameters for most important factors that affect the resistivity of different geological material like porosity, moisture content, dissolved electrolytes, temperature and conductivity of minerals. MASW testing can be performed, which consists of collecting surface-wave data in the field, generating the dispersion curve, and then using iterative modeling to back-calculate the corresponding Vs profile in order to identify the possible hazard zones and can model the structural geology of the study area. Results from the performed geophysical and geotechnical techniques will be used to develop a computational model for different types of weak zones based on geology and structure of landslide. At the end, we will present an efficient approach which will be based upon multi-scale analysis and characterization of slope by incorporating 3D simulation of wave propagation and amplification in order to check the seismic responses of structures using MATLAB Programming.

Keywords- ERT, Geophysics, Geotechnical Engineering, Hydrogeology, MASW, MATLAB, Structural Geology, Slope Stability

I. INTRODUCTION

The term landslide refers to a large variety of mass movements ranging from very slow slides in soils to rock avalanches. Several landslide classifications were proposed and the most widely used at the present time is probably the one which mainly considers the activity (state, distribution, style) and the description of movement (rate, water content, material type). The characterization of these phenomena is not a straightforward problem and may require a large size investigation. Theoretically, the landslide process can be occurred as the result of the disturbance of slope equilibrium. The disturbance of equilibrium of slope is caused by the increasing of the shear stress and the decreasing of the shear strength (Selby, 1991). Classification are based on two major factors contributing towards landslide. Firstly, the factors contributing to high stress i-e removal of lateral support (stream water, weathering, slope increasing), similarly, overloading (rain, soil saturated, fills) and lateral pressure (swelling of clay, water in interstices). Secondly, the factors contributing to low shear strength i-e composition and texture (weak material, uniform grain size, smooth grain shape), physical- chemical reactions, effect of pore water pressure, structure changes and relics structures (joints and cracking). These factors described above are the common factors which used to analyzed the landslide process and hazard (Selby, 1991). In landslide studies, geophysical methods have been successfully applied over the last forty years, making use of resistivity (e.g. Denness et al. 1975; Donnelly et al. 2005), self-potential (e.g. Lapenna et al. 2005), low frequency electromagnetics (e.g. Schmutz et al. 2000), ground-penetrating radar (e.g. Roch et al. 2005). seismic methods (e.g. Bogoslovsky & Ogilvy 1977; Glade et al. 2005). and gravity (e.g. Del Gaudio et al. 2000). Several studies exist comparing different geophysical methods (e.g.
Bichler et al. 2004; Cutlac & Maillol 2004; Sass et al.). Most recent studies include Shear wave velocity (Vs) is sensitive to inhomogeneous media and interfaces. Also, the Electrical Resistivity Tomography (ERT) is an active geophysical method that can provide 2D, 3D and as well as 4D images of the distribution of the soil’s electrical resistivity. In the cases of landslide investigation, the electrical resistivity is used frequently because the factors that mainly affect the resistivity are the type of the soil, the porosity and the water content (Archie, 1942; Reynolds, 1997; Park and Kim, 2005; Biever et al., 2012, Perrone et al., 2014). Numerous studies can be found in the literature regarding the assessment of landslide susceptibility through computation. For example, (Oh et al. 2011)

Applied an adaptive neurofuzzy system (ANFIS) to map the landslide susceptibility (Oh et al., 2011; Gemitzti et al., 2010; Vahidnia et al., 2010). Neuro-fuzzy networks are systems which originate from the union of neural networks and fuzzy inference. The neurofuzzy networks (Masi et al., 2012) are based on fuzzy logic (Zadeh, 1965).

Landslides are a frequently occurring geologic hazard. In the past, they have triggered broad damage to homes, highways, and other assets. Anxiety over geologic hazards is apparent at all levels of government. Federal, state and local establishments are trying to find potential hazards in strength to anticipate and lessen harm to life and property.

Different methods can be used to identify areas along the core where laboratory samples could be selected from the area to obtain data usable in stability analyses, presented by Thompson et al. (2008). Based on the boreholes, trial pits, rock and soil sampling and field tests, the study area can be divided into different heterogeneous reaches by characterizing the area into lithological and morphologic differences. The number of slides occurring in the differing geologic units can then be analyzed.

Several qualitative studies can be applied to the desired core, the first of which is Rock Quality Designation (RQD) procedure. RQD is a standard method for describing the degree of fracturing of a rock mass, as described by Deere (1963). Though the end result of an RQD analysis will be a numerical value, and could therefore be considered a quantitative method, different range of values will describe general rock mass quality. As such, it is must be considered a qualitative approach in this study. By applying similar notion to the GSI (Geological Strength Index) and RMR (Rock Mass Ratings) results, qualitative analysis can be performed.

Comparison between core logging data and hydrogeological conditions of the area can be made. Like, rainfall is one of landslides triggering factors, (Keefer et al., 1987). The water induces movements for two main reasons. Firstly, infiltration increases water pore pressure on the slip surface and remarkably decreasing shear strengths of the landslide mass (Tsao et al., 2005).

Secondly, water creates an increase of weight on the slope and destabilizes the mass by loading (Brusden, 1999). At the slope scale, the presence of slip surfaces induces heterogeneity, where mechanical and hydrogeological properties are modified, that could modify fluid flow (Eberhardt et al., 2005). However, during the movement, the slip surface evolution creates a new repartition of fluid pressure making cavities. Conclusively, water is an excellent solvent, movement coupled with rise and fall of water levels through the pore spaces and fractures within a rock easily dissolve and wash the rock, making the rock weaker along the facture zones. All the above circumstances, coupled together will ignite an excellent path leading to a landslide susceptibility assessment.

The general objective of this work will be to contribute towards a better description and quantification of subsurface heterogeneity for hydrogeological settings in different geological formations by electrical resistivity tomography (ERT), multiple-point-resistance logging with time-lapse, geological and groundwater level data utilization in order to determine rock mechanism. Result will demonstrate the development of landslide model by using integrated shallow geophysical data and models built with traditional geological data (Field Sampling) and hydrogeological conditions. At the end, representation of results within a common MATLAB framework should be performed in order to generate a multi-dimensional assessment model.

A. Scope of Research Work
The overall purpose of our theoretical modeling is to determine hydrogeological structures from sequences in study area. These results will help us assess the relationships between pre and post conditions for the area. More specifically, I hope to address the following research questions:

1) What data required to develop slope stability models using MATLAB (Maths Works)
2) How can we apply the develop models to nearby area using physical parameters of existing data?
3) How to carry out the sensitivity analysis to evaluate the models?
4) How to make ERT and MASW techniques as foundation for the development of structure models of the desire study area?
5) How to incorporate geophysical and geological data in “MathWorks” environment in order to develop true geological structure models for Landslide?

B. Research Objectives
- Identification of likely large-scale landslide through geotechnical core logging methods.
- Processing Geophysical imaging methods for landslides that use electrical currents or induction to probe for fractures system depending on detecting contrasts in resistivity associated with the internal system.
- Low frequency seismic signals can be used to get 2-D tomography profiles of surface soil near landslides. It is possible to identify landslide risks, if geological and geotechnical properties of soil are known.
- What type of features through ERT survey can found as a significant contrast between the feature of interest and the surrounding materials?
This study will present a technique to estimate terrain change volumes quickly and easily, on the basis of geophysical and geological data by using MATLAB programming.

C. Possible Outcomes
- Sensitivity test results, which will aid in the discussion of modeling and analysis.
- An envelope of possible geological structure parameters related to landslide necessary for anomaly positions.
- Comparisons of the different modelled hydrogeology of study area.
- Comparisons of the model results with other hazardous areas for susceptibility assessment.
- The model results will compliment structural information on the basis of field and laboratory tests.

II. RESEARCH METHODOLOGY

A. Preparation Phase
The preparation phase will compromise such as literature study, area selections and fieldwork preparation. The literature study will also be done along the research processes. This study will be carried out in order to obtain better research knowledge and to develop the methodology as well. The literature study will be focusing landslide hazards including causes, slope stability, processes and their impact and hydrogeology of the study area. Moreover, all necessary software related to above mention cases will be installed in order to avoid future complications.

B. Field Work and Data Acquisition (Combined ERT & MASW Techniques)

1) Geophysical Electrical Resistivity Tomography
Near surface geophysical methods such as the ERT method has been widely used in geotechnical applications around the world. This is due to the important information that can be provided for geotechnical Engineers; like the boundaries between geological formations, differences in the rock/soil water saturation, the presence of cavities/faults and the depth of bedrocks…etc. The detection of underground cavities, whether of natural origin such as karstic cavities or of anthropogenic origin such as mining galleries, groundwater channels are of vital importance in land-use planning.

The detection of features through ERT survey is dependent on the presence of a significant contrast between the feature of interest and the surrounding materials. The resistivity of air is extremely high (> 10,000 ohm-m), the resistivity of the unsaturated materials at the site are relatively low (20-400 ohm-m) while fracture zones in saturated rocks have an extremely lower resistivity <5 ohm-m, providing for a significant contrast.

The use of a suitable geophysical prospecting method such as ERT for the identification and characterization of these underground anomalies renders it unnecessary to use destructive methods, such as trenching and drilling boreholes, that are much more expensive and environmentally damaging.

The Electrical Resistivity Tomography (ERT) involves determination of the subsurface distribution of electrical resistivity. This is done by taking a very large number of readings from the ground surface. The varying geo-electric response in the area under investigation enables geophysicists to obtain 2D profiles, L-Shape and 3D images of the distribution of the resistivities under the ground, which makes it a very effective, non-destructive tool for analyzing and characterizing possible discontinuities in the subsoil.

Finally, the subsurface conditions for the chosen site will be evaluated based on the horizontal and vertical variation in subsurface electrical resistivity. Geophysical 3D-ERT will be performed to measure the electrical resistivity along different profile across the area. The measured electrical resistivity will further be used to identify the depth of unconsolidated/less compacted material, fractured/soft materials that correspond to low resistivity values. The collected data during the study will be processed to generate the pseudo-sections of apparent resistivity and later inverted to produce the inverse model resistivity sections. The most important factors which affect the resistivity of different geological material are Porosity, Moisture content, Dissolved electrolytes, Temperature (resistivity decreases with increasing temperature) and Conductivity of minerals. Similarly, air filled voids or caves will show high resistivity because of the high resistivity of the air in case it is found over the ground water level, while it will show very low resistivity than the surrounding material in case if it is found below the groundwater level. The later will then be used to build a contour map of the sections to delineate the anomalies and better understand the subsurface features and underground structures.

<table>
<thead>
<tr>
<th>Table 1: ERT data acquisition methodology procedure</th>
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<tr>
<td><strong>Type of Survey</strong></td>
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<td><strong>Aim of Survey</strong></td>
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<tr>
<td><strong>Total Interval/Area Study</strong></td>
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<tr>
<td><strong>Data Acquisition System</strong></td>
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<td><strong>Data Processing Software</strong></td>
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<td><strong>Final Data Acquired</strong></td>
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C. Landslide Classification on the Basis of Vs30

Shear-wave velocity (Vs) has long been known to be an essential parameter for evaluating the dynamic properties of soils. The average shear-wave velocity in the top 30 m, based on travel time from the surface to a depth of 30 m, is known as Vs30. The classifications will then use to determine the seismic coefficients for earthquake-resistant design. Traditionally, Vs30 is determined by seismic measurements in boreholes, using the down hole, cross-hole, or suspension logging methods. New techniques based on the inversion of surface-wave dispersion data offer the advantage of not requiring boreholes.

Multi-analysis-of-surface-waves (MASW) testing is a proven, non-destructive seismic method that is used to determine the variation of shear-wave velocity (Vs with depth). The basis of this method is the dispersive characteristic of Rayleigh waves when propagated through a layered medium. The Rayleigh-wave phase velocity primarily depends on the material properties (shear-wave velocity, compression-wave velocity or Poisson’s ratio, and mass density) to a depth of one wavelength. The variation of phase velocity with frequency or wavelength is called the dispersion curve. MASW testing consists of collecting surface-wave phase data in the field, generating the dispersion curve, and then using iterative modeling to back-calculate the corresponding Vs profile.

Vs30 is calculated as the time for a shear wave to travel from a depth of 30 m to the ground surface, not the arithmetic average of Vs to a depth of 30 m. As shown in equation (1), the time-averaged Vs30 is calculated as 30 m divided by the sum of the travel times for shear waves to travel through each layer. The travel time for each layer is

\[ \text{Vs30} = 30 / \Sigma (d/Vs) \]  

For example, the Vs30 for a soil profile containing 18 m of soft clay (Vs = 90 m/sec) over 12 m of stiff clay (Vs = 260 m/sec) would be calculated: 30 / (18 / 90 + 12 / 260) = 122 m/sec. The time-average method typically results in a lower Vs30 than the weighted average of velocities of the individual layers: (90 * 18 + 260 * 12) / 30 = 158 m/sec.

D. MASW Limitations

Several methods have been proposed in the literatures to account for higher modes, but the procedures are still not standardized. In fact, the analyses for complex stratigraphy have to be tailored for the specific case and require very experienced analysts. Few limitations related to MASW technique are listed below, by applying different techniques to a similar area it is possible to develop new theoretical models to overcome the situation.

- **Depth**: a function of the lowest frequency vs phase velocity content of the data.
- **Resolution**: decreases with depth.
- **Every dispersion curve**: will generate into a different depth at a different shot.
- **Results**: are highly site dependent. A shear wave velocity of 300 m/s representing loose sand can represent a highly weathered, fractured, weak Siltstone.
- **Results are always relative**. Means weak zones in an area could only be identified relatively by examining all the Vs data over a particular area.
- **Different processors** will have different picking and hence will lead to a different result.

E. Modelling and Analysis

The arrangement of geophysical and geotechnical data will deliver high resolution effects in order to label the subsurface structures of all areas of geologic hazards beneath the proposed area. Applied 3D-Electrical resistivity method is proficient and reliable to get an imaging with high resolution and sufficient accuracy for delineating the contact and interface between different stratigraphic layers beneath the proposed site. The integration of geophysical and geotechnical data will be used to develop initial sample computational models in order to incorporate hydrogeological and structural conditions of the study area.

F. Hydrogeological Modeling

In particular, the meaning of a theoretical model of the landslide structure is of dominant position because unlike natures of landslides have unlike hydrological systems and can react at different sequential scales to the precipitation input (van Asch et al., 1999). The modelling strategy includes concept definition, code formulation, sensitivity analysis, model validation, and finally forecasting (Anderson and Woessner, 1991). Distributed approaches, either 2-D or 3-D, are valuable because they can account for the spatial variability of the landslide material, for the topographic control on the convergence of flows, or for the division of the hydrological system into hydro-geomorphological units (Reid et al., 1988; Miller and Sias, 1998). This research will attempt to validate a distributed physically based hydrogeological code for complex landslides affecting the fine-grained material, characterized by saturated and unsaturated conditions by using MATLAB tools and concepts.

G. Development of Slope Stability Model using MATLAB Programming

Observations and on-site measurements of the meteorological characteristics, the hydrogeology, and displacements at the earthflow began in 1991 (Flageolet et al., 2004). A geophysical and geotechnical investigation combined with a photogrammetric analysis was initiated in 1996 along five cross-sections in order to determine the structure of the accumulated mass (Schmutz et al., 2000). Cross-correlation of all information in a distributed database has allowed the construction of a hydrological and mechanical concept of the earthflow (Malet, 2003). In this section, we will present an efficient approach which will be based upon multi-scale analysis to make a 3D simulation of wave propagation and amplification as well as seismic responses of a landslide. The formulation of the multi-scale modeling will be presented and should be validated computationally by comparing a strong ground motion and a
seismic structure response. The usefulness and applicability of this modeling approach will also be discussed. Currently, many methods are used to analyze the slope stability, such as the limit equilibrium method (LEM), the slip line method, the finite element method (FEM), the mathematical programming approach and the intelligent method, which were developed largely in domestic and foreign engineering practice. Advantage of the composite algorithm for analysis of the slope stability, utilizing FEM to calculate the stress and strain of slopes and using LEM to carry out the stability analysis and adopting several examples of slopes for verification (Chen Cao et al). Slope failures mainly involve the curve sliding surfaces. Thus, we will take the typical cross section perpendicular to the axis as the research object and will analyze it by using a simplified MATLAB method, since it is appropriate for the slope stability analysis of any sliding surface. Based on the results of such analysis, we will hypothesize the surface nature and main trends.

III. METHODOLOGY FLOWCHART

Fig. 1: Representing flowchart for the proposed research methodology

IV. CONCLUSIONS

This research will attempt to validate a distributed physically based hydrogeological code for complex landslides affecting the fine-grained material, characterized by saturated and unsaturated conditions by using MATLAB tools and concepts. Based on the discussed techniques, slope failures predictions can be made in a reliable way.

REFERENCES


[27] Roch, K.-H., Chwatal, W. & E. Brückl (2005): Potentials of monitoring rock fall hazards by GPR: considering as example the results of Salzburg. - In: Landslides 00:1-8

[28] Sass, O., Bell, R. & T Glade: Comparison of georadar, 2D resistivity and traditional techniques for the subsurface exploration of landslides. - In: Geomorphology.


