Resistivity and Seismic Refraction Studies on Kısıklı Landslide (Antalya, Turkey)

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Abstract:

When natural slope is disturbed by human activity such as road construction and infrastructure, continuous landslide monitoring is important to prevent loss of material and life. Therefore, this study aims to determine the landslide material, the possible sliding surface and the influence of groundwater on the landslide occurrence. Low cost monitoring landslide is performed which is vertical electrical sounding (VES) and seismic refraction methods. The case study area is located in the district of Kısıklı (Antalya province) in the Mediterranean Region of Turkey. VES survey were performed using Schlumberger electrode array at six locations. VES results interpretation leads to detect of maximum five geoelectrical layers. First, second and third layers represent saturated and permeable layer, while fourth and fifth layers correspond to an impermeable layer. Seismic refraction measurements were carried out on three profiles. Low velocity and elastic parameters relatively correspond to the permeable materials in near surface with thickness about 4-5 m higher porosity. The integrated of VES and seismic surveys allow mapping the weathered material at depth and providing depth information of the sliding surface which occurs at a depth between approximately 5 m and 20 m.

1. Introduction

Landslide is one of natural hazard that probably impact thousands of deaths and losses of billions of dollars every year [1]. It has different properties according to the cause of occurrence and shape [2]. It occur in the form of slipping, flowing and falling along a certain surface [3]. Therefore landslides are geologic complex formed from the combination of changes in contrast and physical values possessed by the layer [4]. Because of the high cost of geotechnical methods based on direct research, geophysical surveys are the best way to study landslides by determining landslide characteristics [5-7]. Therefore, relatively low cost and noninvasive geophysical methods provide new deals for promptly survey of large areas and produce detailed information about the landslide internal structure [8-10]. Vertical electrical sounding (VES/one-dimensional resistivity) and seismic refraction from field geophysical exploration methods are widely used to investigate the landslide area [11-16]. The success of the resistivity method is connected directly to the electrical resistivity contrast of different lithological units (clay, marl, limestone and etc [13, 17-19]. The first arrivals and their corresponding travel times of seismic refraction are analyzed. With survey of a landslide with geophysical methods may be determined the thickness and lateral extension of slip material, the possible sliding surface, the bedrock depth, the distribution of various materials and the status of groundwater within the slip mass [17, 18, 20-27].

In this study, a landslide occurred after heavy rainfall has been investigated. The maximum amount of rainfall in the landslide area formed between November and February 2010. This landslide occurred on February 2010 in Kısıklı district of Sarıabalı village of Serik town, Antalya...
in Turkey. Annual precipitation between 2008 and 2010 was 273 mm, 1399 mm and 1436 mm, respectively. There was not available daily rainfall data before landslide. In addition, the landslide had taken place after the huge Manavgat-Serik forest fire that broke out in the summer of 2008. Using VES and seismic refraction methods, the thickness of the mass causing landslide, water content, the sliding surface and bedrock structure has been uncovered.

2. Location and Geology

Study area is located in Kısıklı district of Sarıabalı village of Serik town of the province of Antalya in Mediterranean Region of Turkey (Fig. 1). Kısıklı landslide showing an inclination of about 17° is approximately 380 m long, about 90-110 m wide and in an environment with an altitude ranging from 50 m to 160 m. Many man-made structures, such as road along slope, a greenhouse site and several buildings, have been largely damaged by landslide (Fig. 2).

Kısıklı District includes the Ophiolitic Melange of the Antalya Nappes, the Miocene Tepekli Conglomerates and the Karpuzçay Formation [28-30]. The Ophiolitic Melange is mainly composed of limestone blocks, sandstone, marl, chert, shale, serpentinites. The Tepekli Formation around Sarıabalı region outcrops especially along the eastern margin of the Antalya Nappes and consists mainly of well-rounded clastic materials intercalated with mudstones. In places, reefal limestones embedded within the conglomerates can be observed in the area. The Antalya Basin, separated into three sub-basins such as the Manavgat, Köprüçay and Aksu, occurs within the Isparta Angle (Fig. 3) [30]. The Köprüçay Basin including the study area is separated from the Aksu Basin by the late Miocene Aksu Thrust and exists in the central position within the Antalya Basin [31, 32]. The Karpuzçay Formation includes mudstone, siltstone, conglomerates, detritic limestones and rests over the Tepekli Formation [33].

3. Data Collection and Processing

The vertical electrical sounding (VES) method provides one-dimensional (1-D) underground information about the vertical electrical resistivity variation. The classic technique for field VES application is to use Schlumberger electrode array. Five Schlumberger stations were located inside landslide while the remaining one half-Schlumberger station is out landslide area (Fig. 4). Maximum current electrode interval ranges between 100 m and 150 m. VES Schlumberger data were inverted to their equivalent 1-D models composed of horizontal layers using modeling procedures. An algorithm developed by Zohdy [34] was first used to invert the field VES data. Then IP2win software [35] was used to improve the first interpreted results.

The seismic refraction method, which benefits from waves traveling in different parts of the underground, is capable of mapping the boundaries between layers characterized by different seismic velocities. Seismic refraction is a quantitative technique that it provides the seismic velocities as well as determining the depths of different subsurface layers. Two kinds of seismic waves,
namely the P-wave and the S-wave, can assist in the interpretation of geological layers. Three seismic refraction profiles were performed both forward and reverse shooting techniques. The seismic stations were located inside active landslide site (Fig. 4). Seismic refraction data were analyzed graphically, and P- and S- velocities were obtained from slopes of the time-distance graphs. Depths of the layers using travel time equations derived as a function of velocity were computed. Elastic parameters such as modulus of elasticity and Poisson's ratio that describe the subsurface material were calculated by using P- wave and S- wave velocities.

**Figure 4.** Location of the measurement stations; six vertical electrical sounding (VES-1, VES-2, VES-3, VES- 4, VES-5 and VES-6) and three seismic refraction (S1, S2 and S3) stations.

### 4. Results and Discussion

Fig. 5 shows 1-D earth models from the resistivity data carried out at stations VES-1, VES-2, VES-3, VES-4, VES-5 and VES-6. Black lines are field data. Blue lines are 1-D models. Red lines show data calculated from 1-D models. The VES modeling results show that the shallow subsurface in the landslide area can be represented by 3 or 5 layers.

The first geoelectrical layer for VES-1 is characterized by mean 20 Ω m resistivity with thickness of 3 m. The second geoelectrical layer showed to be lower electrical resistivity value (approximately 12 Ωm with thickness of 12 m). The relatively high resistivity value for bottom layer was observed to be about 50 Ωm. The first layer for VES-2 is characterized by mean 60 Ω m resistivity with thickness of 3 m. The remained layers showed to be lower electrical resistivity values (between 17-30 Ωm). The first geoelectrical layer for mid-point VES-3 is characterized by mean 100 Ω m resistivity value with thickness of 2.3 m. The mid-geoelectrical layer showed to be lower electrical resistivity value (between 23 Ωm and 35 Ωm with thickness of approximately 30 m). Bottom layer resistivity was observed to be on the rise. The first layer for VES-4 is characterized by mean 120 Ω m resistivity value with thickness of 1 m. The remained layers showed to be lower electrical resistivity values (between 15-35 Ωm). The first geoelectrical layer for VES-5 is characterized by mean 80 Ω m resistivity value with thickness of 1.7 m. The mid-geoelectrical layer showed to be lower electrical resistivity value (between 20 Ωm and 30 Ωm with thickness of approximately 23 m). The bottom layer showed to be higher resistivity with approximately 100 Ωm. The higher resistivity values about 1300 Ωm were observed for VES-6 outside the landslide disturbed area.

**Figure 5.** The modelled VES curves using 1-D interpretation. Measured data (black curves), calculated data from 1-D model (red curves) and interpreted 1-D models (blue lines).

Fig. 6 shows the resistivity section obtained from combining the VES results. The section illustrates the lateral and vertical variation of electrical resistivity along the profile in landslide area. In particular, the relatively low resistivity values between 13 Ωm and 30 Ωm correspond to impermeable materials, which are clay and water.
The relatively higher values than $30 \, \Omega \text{m}$ resistivity correspond to the saturated mobilized landslide materials at a thickness between 5 m and 20 m. Table 1 shows the P-wave and S-wave velocities, estimated thickness of the layer and dynamic elastic parameter as Poisson’s ratio and modulus of elasticity concluded from the seismic records of three stations inside the landslide site. At seismic stations S1, S2 and S3 on the first layer, average seismic P-wave velocities were stated to be 446, 379 and 571 m/s. Their corresponding thicknesses were noted to be 5 m, 4 m and 4 m, respectively. The second layer, average seismic P-wave velocities were stated to be 1307, 1475 and 1361 m/s, and their corresponding thicknesses were noted to be 13 m, 11 m and 11 m, respectively. Average seismic P-wave velocities for the third layer were stated to be 2072, 2938 and 1996 m/s. Take into account, the modulus of elasticity is more sensitive to porosity changes than seismic wave velocities [36, 37]. This results in the assumption that the decrease in the modulus of elasticity and velocities in near surface is caused by high porosity. The Poisson distribution has values ranging from 0.08 to 0.43 (Table 1). The low Poisson’s ratio (about 0.1) indicate that the material is silty clay and dry, while the high values (about 4 and above) indicate that the water content of the material is high.

### Table 1. Summary of seismic refraction results.

<table>
<thead>
<tr>
<th>Parametric description</th>
<th>Layer</th>
<th>S1 station</th>
<th>S2 station</th>
<th>S3 station</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Forward</td>
<td>Reverse</td>
<td>Forward</td>
</tr>
<tr>
<td>P-wave velocity (m/s)</td>
<td></td>
<td>446</td>
<td>446</td>
<td>379</td>
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<tr>
<td>S-wave velocity (m/s)</td>
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<td>302</td>
<td>246</td>
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<td>5</td>
<td>4</td>
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<tr>
<td>Poisson’s ratio</td>
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<td>0,08</td>
<td>0,14</td>
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<tr>
<td>P-wave velocity (m/s)</td>
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<td>1307</td>
<td>1475</td>
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<tr>
<td>S-wave velocity (m/s)</td>
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<td>611</td>
<td>523</td>
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<tr>
<td>Estimated thickness (m)</td>
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<td>13</td>
<td>13</td>
<td>11</td>
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<td>Modulus of elasticity (kg/cm²)</td>
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<td>18929,40</td>
<td>15008,98</td>
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<tr>
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<td>0,36</td>
<td>0,36</td>
<td>0,43</td>
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<tr>
<td>P-wave velocity (m/s)</td>
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<td>Modulus of elasticity (kg/cm²)</td>
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<td>Poisson’s ratio</td>
<td></td>
<td>0,39</td>
<td>0,39</td>
<td>0,40</td>
</tr>
</tbody>
</table>

Integrated interpretation of the vertical electrical sounding and the seismic refraction tests revealed the internal structure of the disturbed landslide zone. Fig. 7 shows the slope section interpreted from the integration of two techniques. The slope cross-section permits to clearly define the slip/sliding surface, the thickness of the saturated landslide material and an impermeable layer consisting of clay and water.

5. Conclusion

Based on the vertical electrical soundings, subsurface in landslide disturbed area is represented by 3-5 geoelectrical layers characterized to be electrical resistivity values ranging from 10 Ωm and 120 Ωm within a total depth of 40 m. On the other hand, the resistivity values outside the landslide disturbed area were observed to be higher. The resistivity section obtained from the VES results illustrates the lateral and vertical variations in electrical resistivity. The relatively low resistivity values between 13 Ωm and 30 Ωm correspond to impermeable materials, which are determined by content of clay and water.
particularly. The relatively higher values than 30 \(\Omega\text{m}\) resistivity correspond to the saturated mobilized landslide materials at a thickness between 5 m and 20 m.

According to the results of the seismic refraction survey, the depth of about 15 m of subsurface in the landslide site is represented by 3 seismic layers. The layers within the landslide disturbed site are characterized by that the P- and S- velocities between 379-2938 m/s and 246-1020 m/s respectively. The decrease in seismic wave velocities and the modulus of elasticity in near surface is caused by high porosity. The sliding surface between saturated and impermeable zones is at a depth between 5 m and 20 m with 1.5 m of soil material overlying between 3.5 m and 18.5 m of the mobilizing landslide material, which is presence of saturated and permeable material.

![Figure 7. The landslide section obtained from the analysis of resistivity and seismic data.](image)

Because of landslide occur after a huge Manavgat-Şerik forest fire (summer 2008), future research is important for understanding landslide behavior in that particular area. The integrated interpretation of 1-D electrical resistivity and seismic refraction tests is useful to figure out the subsurface structure in landslide direction. The investigation results will provide information for a stability assessment of the landslide area in the future.

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