LANDSLIDE RISK STUDY USING APPARENT RESISTIVITY "REAL SECTION". CASE STUDY ARBERIA QUARTER IN PRISHTINA CITY, KOSOVO

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Abstract. Landslides are phenomena that can be very complex and their study requires geological and geomorphological mapping, geotechnical and geodetic study and also geophysical investigation. Geophysical techniques that can provide valuable information on physical parameters, may be directly or indirectly an indicator for the mechanism of landslide phenomena (JONGMANS & GARAMBOIS, 2007). The Electrical Tomography is known to help in engineering geology problems due to electrical resistivity variations between the basement rocks and overlaying sediments, which form an unconsolidated cover. As a rule, the basement rocks are more compact and show higher electrical resistivity values, compared to the loose sediments of the cover, consisting of clays, silts and sands. The first several meters though, in dry season, have higher resistivity values compared to the sediments of the cover saturated with water (*below water table*). In this paper the geophysical study of a landslide taking place in Prishtina city, Kosovo, is presented.

Keywords: Landslides, electrical tomography, Resistivity “Real Section”, mapping.

Rezumat. Studiul riscului de alunecări de teren pe baza rezistivității aparente „Secțiunea reală”. Studiu de caz cartierul Arberia din orașul Prishtina, Kosovo. Alunecările de teren sunt fenomene care pot fi foarte complexe și studiul acestora necesită cartografierea geologică și geomorfologică, studiul geotehnic și geodezic, precum și cercetare geofizică. Tehnicile geofizice care pot furniza informații valoroase despre parametrii fizici pot fi, direct sau indirect, un indicator al mecanismului fenomenelor de alunecări de teren (JONGMANS & GARAMBOIS, 2007). Tomografia electrică este utilizată în rezolvarea problemelor de inginerie geologică datorită variațiilor de rezistivitate electrică dintre rocile din subsol şi sedimentele suprapuse, care formează un strat neconsolidat. De regulă, rocile din subsol sunt mai compacte şi prezintă valori mai mari ale rezistivității electrice, comparativ cu sedimentele neconsolidate de la suprafață, constând din argile, silice şi nisipuri. Primii câțiva metri, în sezonul uscat, au valori mai mari ale rezistivității comparativ cu sedimentele de la suprafață care sunt saturate cu apă (*sub nivelul freaticului*). În această lucrare este prezentat studiul geofizic al unei alunecări de teren care are loc în orașul Prishtina, Kosovo.

Cuvinte cheie: alunecări de teren, tomografie electrică, rezistivitate „Secțiunea reală”, cartografiere.

INTRODUCTION

The term landslide refers to a large variety of mass movements ranging from very slow slides in soils to rock avalanches. Landslides affect all geological materials and exhibit a large variety of shapes and volumes and might have a high socioeconomically impact also in terms of loss of lives and damage. The characterization of these phenomena is not a straightforward problem and may require a large volume of investigation. Ground modifications due to a landslide are likely to generate changes of the physical parameters characterizing the ground, which can be used to map the landslide body and to monitor its motion.

The problem gets serious when in the landslide areas are located structures and buildings. This is the case that is treated in this paper (Fig. 1).

Figure 1. Schematic map of the surveyed area and proposed survey lines (Google Earth, modified by Karriqi).

From an in situ observation many spots affected by the landslide may be identified. That is expressed mainly in road damages, but may be a problem in structures also (Photo 1).

The target of this survey was to study the compactness of Quaternary sediments overlaying the basement rocks, as well as their total thickness, in the area of Arberia quarter, which has an increased risk for landslides. The required depth of investigation was about 50 m.

In situ geophysical techniques are less invasive than the ground based techniques (piezometer, inclinometer, laboratory tests, etc.) and provide information integrated on a greater volume of the ground, thus overcoming the point-scale character of classic geotechnical measurements. Electrical Resistivity Tomography (ERT) has been increasingly applied for landslides investigation among other geophysical techniques. Using ERT we can obtain 2D resistivity images of the subsoil. Analysis and interpretation of these electrical images allow the identification of resistivity contrasts that can be mainly due to the lithological nature of the terrains and the water content variation.

Photo 1. Landslide spot evidenced by road damages (original).

GEOLOGICAL SETTINGS

Arberia quarter is located in the western part of Prishtina city. Geologically, it belongs to Vardar zone, covered by Pleistocene formations.

The Pleistocene formations are found in the lowest parts of the lacustrine sediments of Kosovo basin, between 580 m and 600 m elevations. The actual geomorphological analysis of this area indicates that these sediments developed into two lacustrine phases (Fig. 2).

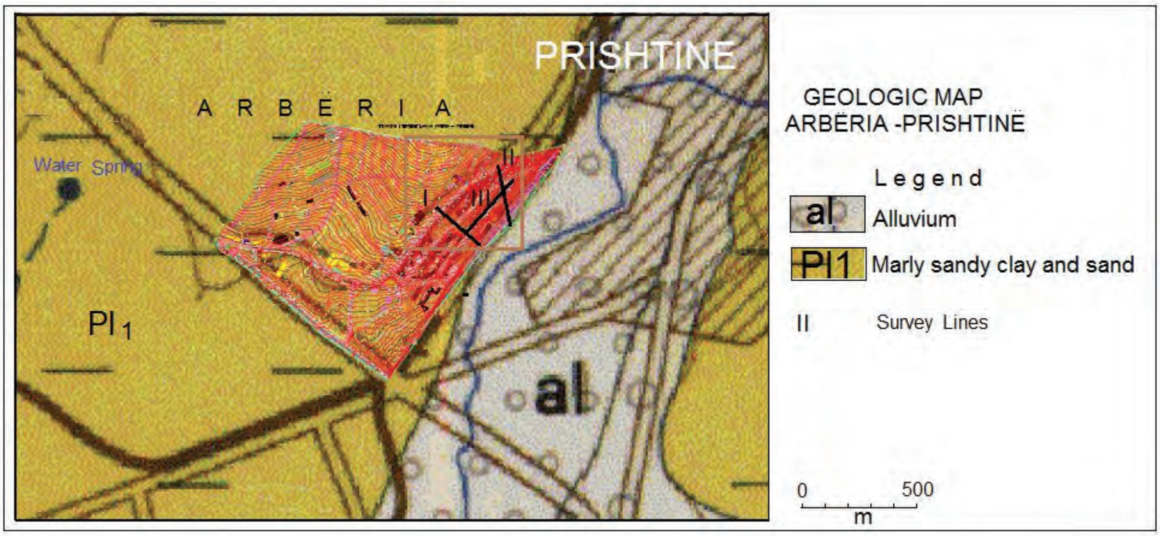

Figure 2. Geological map of Arberia, Prishtina, 1:200 000 (Geological map of Kosovo).

In Arberia quarter, the Pleistocene sediments have a vast distribution in the northern and western part and they are represented by clays, sands, clay sands and silts. The total thickness of these sediments is not defined, because there are not available dedicated deep drillings for this purpose down to basement rocks. In the western part of the area, a water spring of limited yield exists.

The alluvium formations are extended alongside the river flow of Prishtina. In the flat parts, there developed alluvium deposits (present river deposits), represented by sands, silts and gravels.

RESISTIVITY "REAL SECTION" TECHNIQUE

The methodology of electrical prospecting with "Real Section" technique is presented in the paper of Langore, Alikaj & Gjovreku published in the "Geophysical Prospecting" journal of EAGE, in 1989. The "Real Section" is an original technique introduced by P. Alikaj in 1978, which provides a very good corroboration between the surveyed electrical parameters and the geological structure in a section. The basis of "Real Section" survey stands in electrical observations with multiple length gradient arrays, from the longest to the shortest current electrode separations, maintaining the same lengths of potential dipoles. The Induced Polarization (IP) or Apparent Resistivity data on every station are plotted at points located at approximate depth of investigation Hi, which is determined experimentally over a known geological cross section. In our experience, Hi = (0.125 – 0.2 AB), where AB is the length of the current dipole. This is compatible with the theoretical studies on depth of investigations with direct current arrays in homogeneous media (ROY & APPARAO 1971), or of heterogeneous media (FRASHËRI, 1987). The "Real Section" concept as presented (in quotation marks) is not an exact electrical section of the underlying medium; it is rather a convenient schematic plot of electrical parameters, which has proved successful in many geological environments in Albania, Canada, USA, Latin America and in many other parts of the world providing very accurate results in mineral exploration, engineering geology, hydrogeological and environmental studies (FRASHËRI et al., 1995; ROTH, 1997; ALIKAJ et al., 2012; KARRIQI & ALIKAJ, 2011, 2012).

The IP/Resistivity "Real Section" observations can be carried out with any internal electrical field arrays, like gradient, Schlumberger and Wenner; however, due to simple anomaly shape, high resolution and high output measurements, it is best performed with the gradient array.

The "Real Section" is not a mathematical inversion of surveyed parameters, but through recent special algorithms we have included, which make proper corrections (in current lines distribution, as well as terrain correction) in plotting points of measurements at depth, provides very accurate location of apparent electrical parameters in a section. To distinguish it from a traditional raw "Real Section" presentation, which does not have such corrections, we have conventionally called it "Physical Inversion" of IP or Resistivity "Real Section".

FIELD PROCEDURE OF ELECTRICAL SURVEY

The Electrical Tomography is known to help in engineering geology problems due to electrical resistivity variations between the basement rocks and overlaying sediments which form an unconsolidated cover. As a rule, the basement rocks are more compact and present higher electrical resistivity values, compared to the loose sediments of the cover, consisting of clays, silts and sands.

The first several meters of the ground, in the dry season, show higher resistivity values compared to the sediments of the cover saturated with water (below water table). The survey was performed with "Real Section" technique (ALIKAJ, 2014; LANGORE et al., 1989), which provides a good vertical and horizontal resolution for the maximum required depth of investigation, in our case 50 - 60 m, with 10 m spacing between stations.

The measurements were carried out with five or six multiple gradient arrays, with spacings between the current injection electrodes starting from AB = 300 m to AB = 50 m. Lines 1 and 2 (Fig. 3) were located in NW - SE direction with different azimuths and were surveyed in an interval of 200 m, while line 3 was located in NW - SW direction, with a survey length of 300 m.

The measurements were carried out with Time Domain transmitter VIP - 10 kW (*Iris Instruments*, France), which is the most powerful transmitter these days in the market for deep IP/Resistivity surveys. The reason to use this transmitter is that being within the city area, the resistivity measurements are strongly influenced by electrical noise caused by a large number of electrical equipments that use DC or AC power for various purposes. This transmitter provides up to 20 Amperes and 3000 Volts, which can minimize the external electrical noise in the total value of surveyed signal. All other less powerful transmitters would be almost useless in such situation. As receiver it was used ELREC PRO 10 (*Iris Instruments*, France), which is one of the best receivers in the market for high accuracy in IP/resistivity measurements. This receiver has ten simultaneous receiving dipoles, which enables higher measurement output as well. A transmitter time (pulse) of T = 2 sec. and receiving time t = 2 sec. was used for these measurements. Data processing of "Real Section" survey includes proprietary software (*Physical Inversion*) which, in addition to terrain correction, includes the shape of underground current lines distribution between current electrodes.

In addition to the electrical noise caused by the city activity, the proximity of survey lines to buildings, roads, sidewalks, waterlines and other man-made objects, markedly distorts the signal generated by the underground geological section. Through a careful analysis of every apparent resistivity measurements, several intensely distorted values have been excluded from data presentation. The lack of these distorted measurements markedly improves the general correlation between the "Real Section" resistivity survey and the lithological features. However, a complete distortion correction is impossible to conduct and it might influence to a certain degree some of the presented values of apparent resistivity.

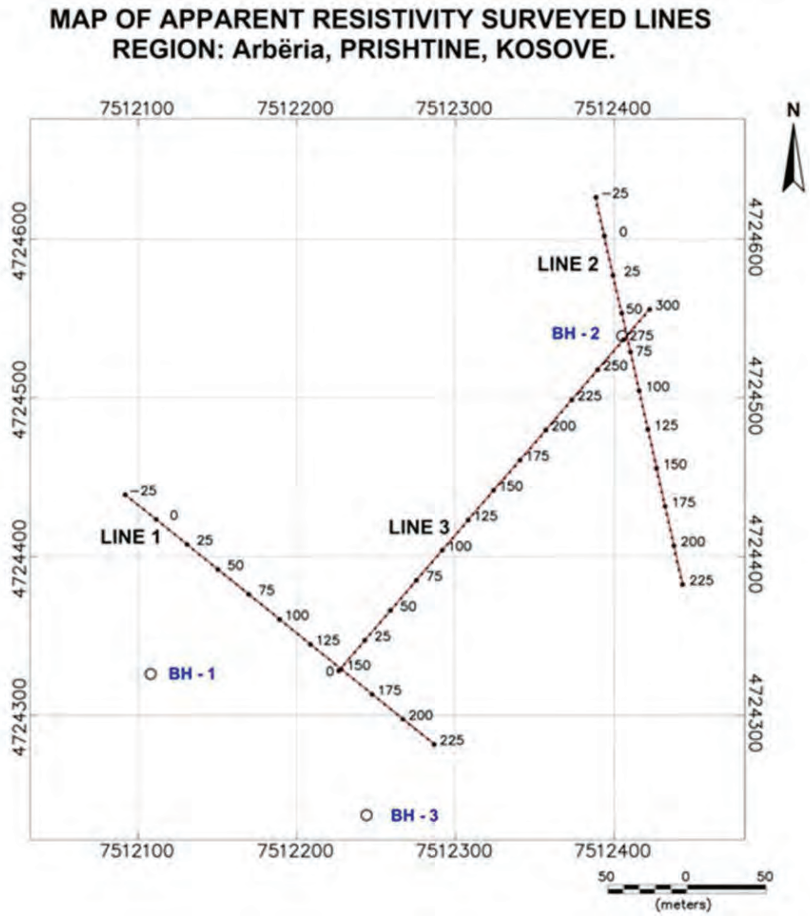

Figure 3. Map of apparent resistivity surveyed lines.

RESULTS AND DISCUSSION

In Figures 4, 5 and 6, there are presented the Physical Inversions of apparent resistivity “Real Sections“ obtained respectively on Lines 1, 2 and 3. Physical Inversion of Line 1 (Fig. 4) is characterized by generally low resistivity values, in a narrow range between 3 and 14 ohm·m.

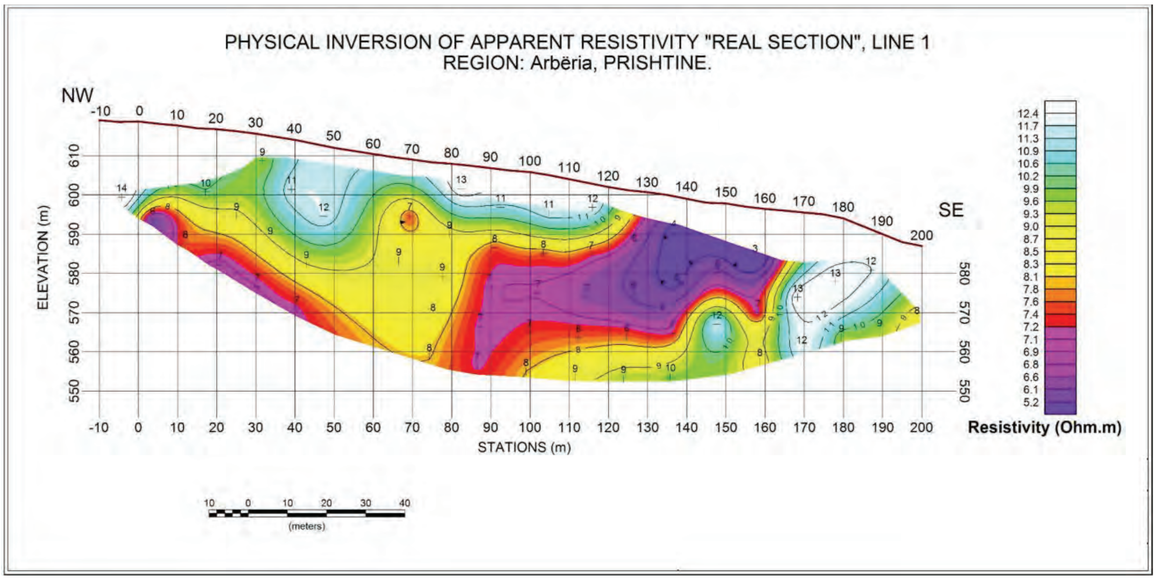

Figure 4. Physical Inversion of apparent resistivity “Real Section” on Line 1.

The lowest values are obtained near the surface, between stations 125 and 165 (dark pink color). These values are interpreted as related to mostly clay formations, which continue at depth towards the NW direction. In the sector between stations 30 and 120, near the surface, there are noticed rather higher resistivity values (11 - 13 ohm·m), which are likely to be related to the presence of some thin layers of coarser sediments (sand/gravel) or dumped soils.

At depth in the SE corner, the resistivity values tend to increase a little bit (13 ohm·m), indicating that the formations are slightly more compact or the section becomes coarser. However, down to 50 - 60 m in the center of section, it continues the same unconsolidated sedimentary formation.

The closest boreholes to this section (No. 1 and No. 3) are too shallow (less than 30 m) to verify this situation at depth. The presence of unconsolidated formations in this section and the terrain steepness (about 16 %) should be always considered as a potential risk for landslides in this area.

The Physical Inversion of Line 2 (Fig. 5) has some similarities to the previous section, but the range of resistivity values is broader (2 - 45 ohm·m). The lowest values (2 - 4 ohm·m) are located near the surface, between stations 50 - 70 and 120 - 135, forming a prominent arc of low resistivity down to 20 - 30 m. This arc is likely to be connected with the presence of a thick formation of mostly wet clays near the surface, which is a potential risk for landslides due to the terrain steepness in this sector. This is clearly proved by a landslide with an amplitude of about 50 cm, located alongside the asphalt road, as seen on Photo 1.

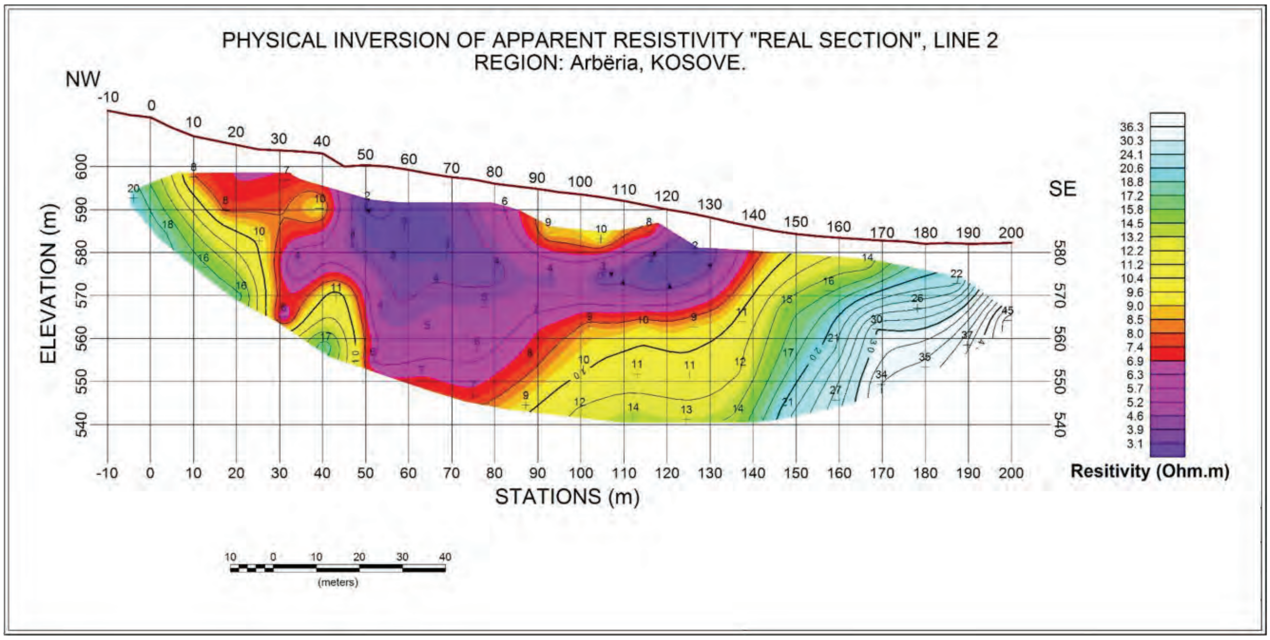

Figure 5. Physical Inversion of apparent resistivity “Real Section” on Line 2.

The landslide is on station 80. The borehole No. 2, located on station 70 of this line, clearly proves the presence of a mostly clay matrix down to 29 m depth.

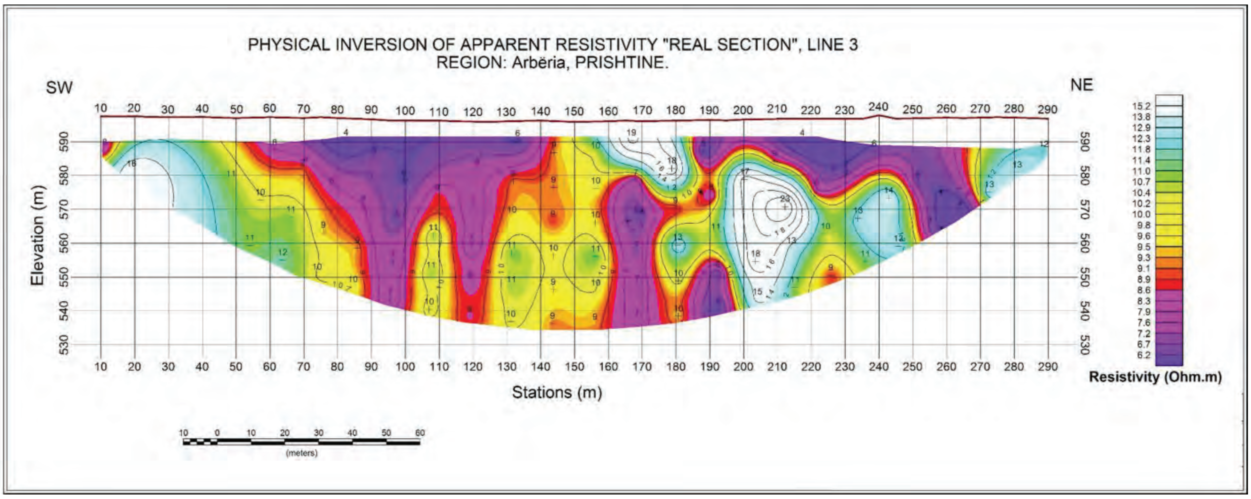

Figure 6. Physical Inversion of apparent resistivity “Real Section” on Line 3.

It is important to note that the highest values of apparent resistivity parameter are located in the SE edge of the section at depth (up to 45 ohm·m). The increased resistivity values form an arc on both sides of the section. In the center though, the values remain lower even below 50 m depth. We assume that the increased resistivity values on both sides of the section are likely to be connected with more compact formations, more stable in terms of landslides. A borehole of about 30 m on station 160 or another one of 80 m in the center of section would prove this interpretation.

Physical Inversion of Line 3 (Fig. 6) represents a longitudinal section, which is orthogonal to Line 1 and rather inclined to Line 2.

This line is more affected by man-made objects, because it is located only 1 m parallel to the sidewalk of a paved road. However, the variation of resistivity values, between 4 ohm·m and 16 ohm·m, indicates that the unconsolidated sediments are present at depths below 60 m in this section. The road landslide mentioned in previous line corresponds to station 260 in this line, which is characterized by low resistivity values.

CONCLUSIONS

The Electrical Tomography with apparent resistivity “Real Section” technique proved to be effective in delineating the thickness and variations of the unconsolidated Pleistocene sedimentary formations of Arberia quarter in Prishtina city, although the presence of man-made objects sometimes distorted the surveyed data. These data were excluded from the presentations in sections.

Based on the surveys performed on three lines in this area, it was concluded that the unconsolidated sedimentary formations (clay, sand, silt, gravel) continue at depths below 50 m in most zones. Due to terrain steepness, the terrain above these formations is prone to landslides of various amplitudes, which should be carefully considered in the development of the urbanistic plan of the area.

The most affected sectors in the surveyed lines are the ones with the lowest electrical resistivity values (below 8 ohm·m), which probably correspond to water saturated clays.

The sector from station 150 to station 200 on Line 2 is more stable in terms of landslides, not only due to terrain steepness, but also due to more compact formations, as indicated by higher resistivity values.

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