2D Electrical Resistivity Tomography of a Landslide in Garhwal Himalaya

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Summary

2D electrical resistivity tomography has been applied to a landslide investigation in Garhwal Himalaya. Three representative Wenner-Schlumberger profiles spanning the landslide are presented. Generally, resistivity tomograms show the presence of slip zones at a depth range of 10 to 20 m from ground level. The inferred lithological depth sections clearly outline the importance of resistivity tomography in landslide studies, especially in hazard assessment on a detailed scale.

Introduction

In recent years, application of geophysics for landslide studies has widely increased. A landslide is a complex geologic body composed of a combination of layers having contrasting and gradational physical properties (Bogoslovsky and Ogilvy, 1977). The main problems in landslide characterization are related to the subsurface geology and hydrological conditions and in many cases the information on the depth and the lateral continuity of the sliding surfaces can not be obtained through boreholes or geological investigations. However, geophysical investigations can provide in situ subsurface conditions, which in turn can be translated into geotechnical information on the parameters of the subsoil towards a complete understanding of the physical behavior of a slope. Feasibility of various direct and indirect geophysical techniques resolve details of sliding masses, such as down slope movement, thickness, relief of bedrock, depth of water table and internal composition of the sliding mass (Bogoslovsky et al.1977; Mills, 1990; Caris and Van Asch, 1991; Hermann et al. (2000; Hack, 2001; Israil and Pachauri, 2003; Lapena et al. 2003; Bichler et al. 2004). Recently, considerable attention has been devoted to the role of Electrical Resistivity Tomography (ERT) or electrical imaging (Griffiths and Barker 1993; Loke and Barker 1996; Jongmans et al. 2000) and the self-potential (SP) techniques (Bogoslovsky and Ogilvy 1977; Patella et al. 1995) in landslide investigations. These methods combine low costs, fast field survey procedures and high-resolution imaging of electrical properties of the subsurface.

Electrical resistivity surveys have progressed from the conventional vertical soundings (Schlumberger method), which provide layer depths and resistivities at a single place, to techniques that provide 2D and even 3D high resolution electrical images of the subsurface (Griffiths and Barker 1993; Dahlin 1996). This development started with the introduction of geoelectrical tomography field systems and was soon followed by post-processing and inversion algorithms, to transform the measured apparent resistivity pseudo-section in a true Resistivity cross-section model or ERT (Loke and Barker 1996).

Objectives

Here, the application of 2D resistivity imaging (Loke and Barker, 1996) method to an active land slide, known as Naitwar Bazar Landslide, located near the confluence of the River Tons and Rupin (31º03´59½ N & 78º06´12½ E) at Km. +11 of Mori – Sankri Motor road of Uttarkashi district, Uttaranchal. The achieved results in the form of true resistivity depth sections have successfully identified the possible sliding surface including trapped dislodged boulders within sliding mass and entrapped pockets of groundwater.

Location and Geology

The landslide under investigation is known as Naitwar Bazar Landslide, located near the confluence of the River Tons and Rupin (31º03´59½ N & 78º06´12½ E), is at Km. +11 of Mori – Sankri Motor road of Uttarkashi district of Uttaranchal. The topography is of moderately sloping with an average of 45 – 55º gradiant. The elevation ranges between 1290 m. at the river side and 1800 m towards the terrace side which is around 1.5 km. in length and 1.2 km wide at its maximum. The region experiences pleasant weather during the summer while winter is harsh. The average temperature varies from 5 to 25º C. The average annual rainfall is between 1000 mm to 1500 mm. Most of the rain occurs during the months of July to September. The entire belt experiences light to heavy snowfall during the winters.

The area under investigation belongs to Jutogh Formation of Himachal Himalaya (Ganesan and Verma, 1978, 1981). Allochthonous Jutogh belt of crystalline zone is a major belt of tightly folded metamorphic rocks namely schistose quartzite, garnetiferous mica schist with quartzite, mica schist, quartz – biotite schist, carbonaceous schist with occasional marble bands, hornblende schist, amphibolites etc. It is bounded to the south by a major low angle thrust, named the Jutogh thrust in Himachal Pradesh and Main Central Thrust in the east. This crystalline zone forms the basement of the Proterozoic to Phenorozoic sediments of the Tethyan basin of higher Kumaon Himalaya and Spiti – Zanskar basin of the Greater Himalaya in the North. The major rock types at landslide are mica schist and quartz – biotite schist.

The Naitwar Bazar Landslide started moving on 4th September 2004. The Terrace is around 120 m high from the river level and mainly consists of weathered Mica Schist and quartz – biotite schist.

Electrical Resistivity Tomography Method

Current multi-electrode (usually 72-electrode or 48-electrode systems), micro-processor based 2-D Resistivity Imaging System offers good opportunity to obtain the resistivity images to reasonable depths around 50-100 m (much depends on local geological conditions) below the sliding mass or at toe / crown level. For a good lateral and vertical resolution, hybrid Wenner-Schlumberger profiling is preferred. The Electrical Resistivity Tomography (ERT) or electrical imaging is a Geoelectrical method widely applied to obtain 2D and 3D high resolution images of the complex geology (Griffiths and Barker 1993; Dahlin 1996). A multi-electrode Resistivity imaging system, SYSCAL Junior switch 72 of IRIS make was used in the study region (Fig.1). A *GARMIN* make GPS was used for the position location of all the 72 electrodes and used for the topographic correction for all the profiles in *Res2Dinv* program.

Resistivity data were collected using Wenner – Schlumberger (VES) array configuration with electrode spacing of 2 – 5 m, during the pre monsoon period. For each profile, more than 1200 measurements were acquired. Topographic corrections and 2D inversion model were performed using ***Res2Dinv*** of GEOTOMO. This resistivity inversion software is based on the least-square method proposed by Loke and Barker (1996). In all inversion attempts the number of iteration was set to 7.

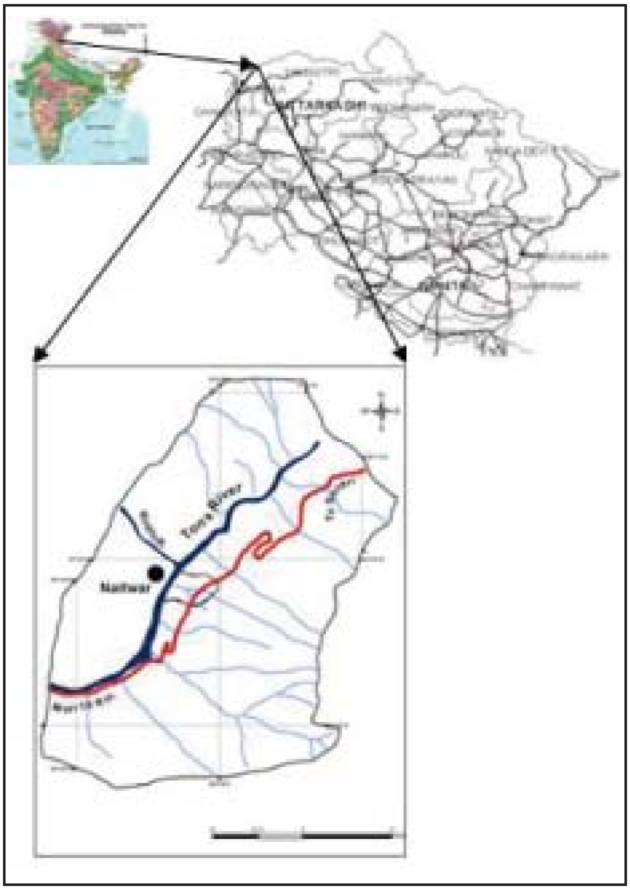

Fig. 1: Location map of the study area. Black dotted line on the map is limit of the landslide.

A total of six resistivity tomography profiles (Fig. 2) were carried out: two parallel to the landslide body (AA´ and BB´), two perpendicular to the landslide direction on the terrace (CC´ and DD´) and two more at the toe region in parallel to landslide direction (EE´ & FF´). In Fig. 3 (A, B, C) we include three interpreted true model resistivity sections along profiles AA', CC' and EE'. By utilizing RES2DINV software, apparent resistivity profile data is interpreted. To have uniformity in the interpretation of different true resistivity sections along profiles, a common colour code has been evolved and adopted for presentation of results. The adopted colour code answers the key parameters of landslide process like presence of low resistive clay/ clayey sand horizons, demarcation of locked groundwater pockets and identification of dislodged boulders and debris. Based on outcrops and geoelectrical literature (Telford et al. 1990), Table 1 is prepared wherein tentative true resistivity versus subsurface lithology appears. It has been used in the preparation of subsurface lithological sections along AA', CC' and EE' profiles (Ref. Fig.1) and also inferred hydrological regime within the slide mass.

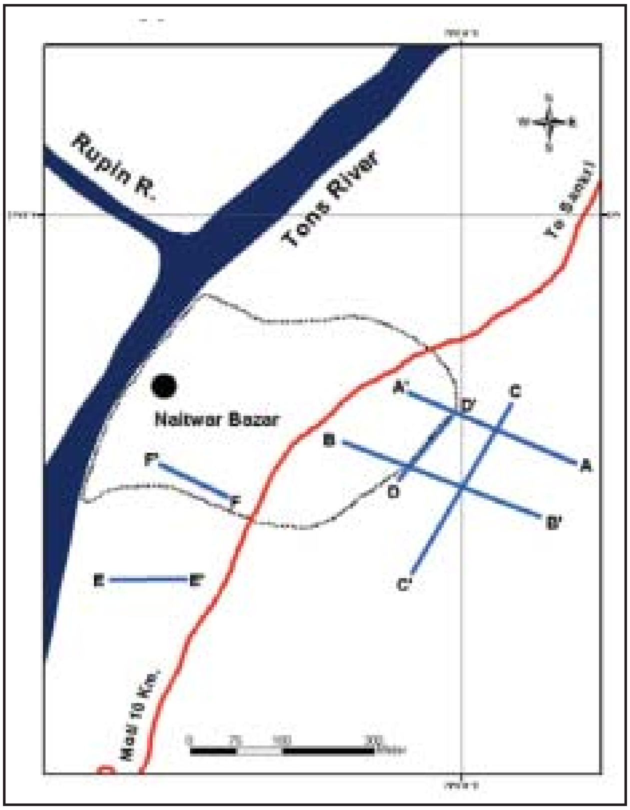

Fig.2: Map showing Electrical resistivity survey lines AA' to FF'). Black dotted line indicates the extent of active sldie zone.

Results

1. Profile AA'

The obtained electrical resistivity tomogram (ERT) along profile AA' (Fig. 3a) actually has a resistivity range of 26 - 26994 ohm-m. The colour code demarcates the resistivity inhomogenities as per the true resistivity ranges of subsurface earth materials in situ. A layer of relatively low resistivity in the range 200 – 300 . m is observed at the lower part of the head scarp, at shallow depth of 5 to 15 m. and is absent in the upper part. A relatively higher resistivity of 1000 – 3000 . m zone can be observed on the sides and upper part. Using Table 1, a tentative lithological depth section (Fig. 3b) summarizes the results. Fresh quartz-biotite schist is not present. Only moderately weathered and semi-weathered schists are present in the slide mass. In the toe portion, at shallow depth wet sandy clay is spotted. Evidently, no pockets of groundwater within the sliding mass exist. This could mean that the slope is stable at present and probably do not pose any imminent threat.

Table 1: Tentative true resistivity – lithology conversion table

Rock type	Resistivity in . m.
Clay	< 30
Wet Sandy Clay	30 - 80
Wet Sand / Saturated sand	80 - 200
Highly Weathered Schist	200-300
Semi-Weathered Schist	300 - 1000
Moderately -Weathered Schist	1000-4000
Relatively Fresh Schist	> 4000
Fresh Groundwater	80-120

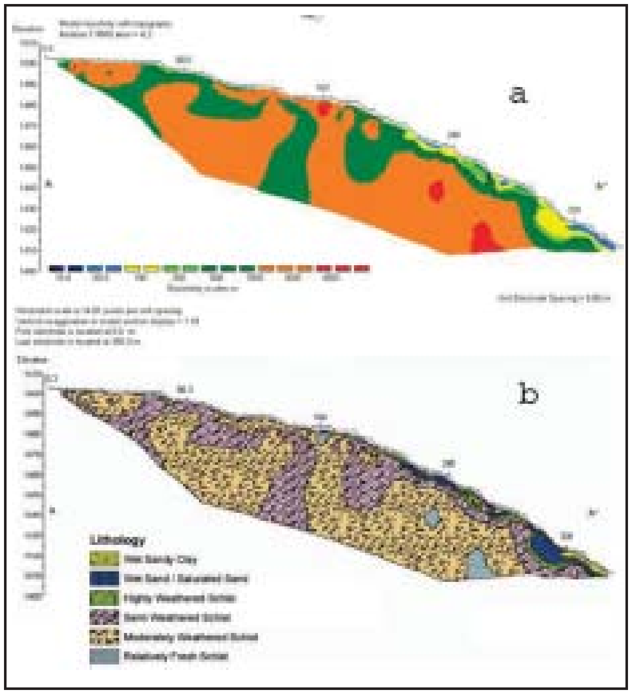

Fig. 3: Interpreted a) geoelectric section and b) derived lithological section of profile AA'.

2. Profile CC'

In ERT along CC' (Fig. 4a) which is perpendicular to the landslide direction, was conducted on the terrace region, out side of the active slide zone and gives better perception of depth variation of low to high resistivity zones. Similar to the profile AA', a low resistivity zones was also observed here. In CC' the low resistivity zone (ñ < 200 – 300) is at greater depth than AA'. In CC' high resistivity zone of ft > 4000 . m is observed at two regions, middle & left part of the profile. In ERT along CC' the thickness of low resistivity zone (ñ < 200 – 300) is much higher, where recently cracks have been developed on the buildings. As per earlier procedure prepared lithological depth section (Fig.

4b) outline the vulnerability of highly weathered schists resting on semi-weathered ones (lateral distance range 120 – 360 m) in the depth range of 20m for a possible fresh slide in near future.

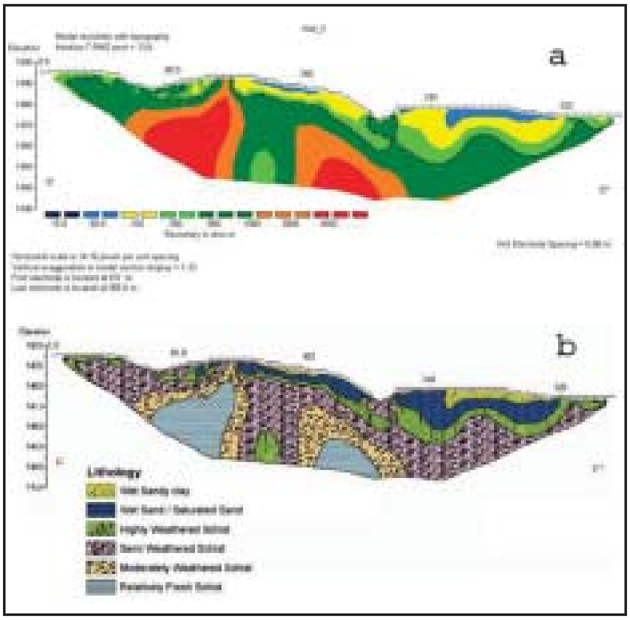

Fig. 4 : Interpreted a) geoelectric section and b) derived lithological section of profile CC'.

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3. Profile EE'

The ERT along profile EE' (Fig. 5a) was conducted near the river, is out side of the present active slide zone. In case of EE' the depth of investigation was only of 20 m. in deep, hence, depth variation of resistivity was not observed. In major part of the ERT, a comparative high resistivity (ñ < 300 – 1000) zone was observed. But presence of a low resistivity zone at the central part at a depth of 15m indicates possibilities of low resistivity zone at a greater depth. Presence of such low resistivity zone at such depth indicates the presence of groundwater in pockets, which may lead to fresh slides in the area. Figure 5b presents a possible depth-wise lithological section. The vulnerability of this slope is clearly evident in Fig.5b. However, an ERT with higher electrode separation, immediately after monsoon may be useful to better characterization of the slope.

All the geoelectrical images (Figs.3a,4a and 5a) except EE' (Fig.5) show presence of a comparatively low resistivity zone of range 200 – 300 . m comprising highly weathered schist may be responsible for respective slope

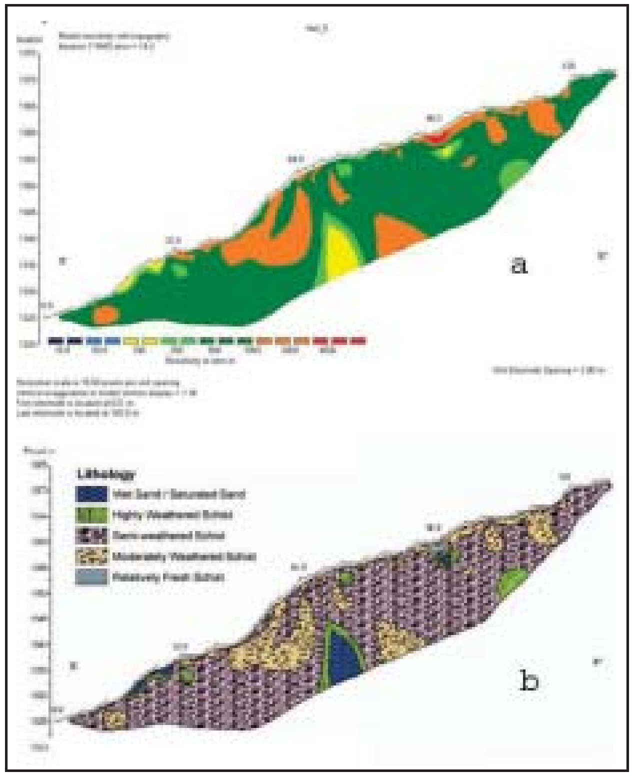

Fig. 5: Interpreted a) geoelectric section and b) derived lithological section of profile EE'.

instability. In case of AA' (Fig. 3) absence of this layer in the slided part and exposure of moderately weathered schist in the scarp zone is supportive for this argument. Further, the same low resistivity zone is comparatively thicker in case of profile CC' (Fig. 4). In Figs. 3a, 4a and 5a, the contact between the low resistive highly weathered schist and comparatively high resistive moderately weathered schist is marked by black dash line. This type of demarcation suits the hazard assessment in situ locally. Further, it has been observed that the low resistivity layer occurs in depth range of 10 to 20 m below ground level.

Conclusions

The present study has utilized new electrical resistivity tomography method on an active landslide area in Garhwal Himalayan region. This method combines low cost and fast field survey procedures with high resolution imaging of electrical properties of sub-surface. Out of six profiles surveyed, we have presented three of them. This selection is to focus the role of electrical imaging in landslide process in situ. The achieved results clearly stress the importance of electrical tomography in landslide hazard assessment for active slides. Repetitive resistivity imaging can help better characterization of landslide hazard and facilitate subsequent geotechnical studies in a meaningful way for design of corrective measures. Electrical Resistivity Tomography integrated with geological information has proved to be a powerful tool for the investigation of landslides in areas of complex geology.

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