



Electrical Resistivity Tomography and Gravity Studies for Active Landslide Characterisation at Naitwar, Garhwal Himalaya, India.

Prof. Rambhatla G. Sastry, Suman K Mondal, Param K Gautam, Ashol K. Pachaur
IIT, Roorkee

Summary

A geophysical investigation was applied to an area, subjected to a large active landslide in the region Naitwar, Uttarakhand, India. The joint application of electrical resistivity tomography (ERT) and gravity studies has led to the detection of potential sliding surface, hydro-geological conditions of the slope up to a depth of 50 m and depth of the hard rock. The test has clearly outlined the utility of ERT & gravity methods in landslide investigations. More over these methods helped in understanding the active landslides processes and hazard assessment in detailed scale, characterised by low grade metamorphic rocks in a complex geological setting.

Introduction

In the Himalayan region, landslides occur at variety of scales and types. The complex nature of many landslides necessitates the need for detailed geophysical investigations (Bogoslovsky and Ogilvy, 1977a). Various direct and indirect geophysical methods, viz. electrical resistivity tomography (ERT) (Fraseri et al. 1998, Godio and Bottino, 2001, Lapenna et al. 2003, 2005), Self Potential method (Bogoslovsky et al. 1977b, Colangelo et al. 2006), Magnetometric (Bogoslovsky et al. 1977b), Seismic (Ferrucci et al. 2000) and integrated methods (Mauritsch et al. 2000, Bichler et al, 2004, Lapenna et al. 2005) have been successfully described and reviewed by many workers for landslide investigation. Here an integrated geophysical approach for detailed study of an active landslide of Naitwar bazar (Uttarakhand) is presented.

Location and Geological Setting

The Naitwar Bazar Landslide is active since 4th September 2004. The landslide is located near the village Naitwar of Mori block of Uttarkashi district of Uttarakhand, immediate upstream of the confluence of the River Tons and Rupin (31°03'59" N & 78°06'12" E). The site is at Km. +11 of Mori – Sankri motor road, and at a distance of approximately 180 Km. from Dehradun (Figure 1).

The topography in the vicinity of landslide is of moderate sloping in the range of 45 – 55°. The elevation ranges between 1290 to 1500 m. The digital elevation model of the area is depicted in Figure 2. The annual temperature varies from 5 to 25° C. The average annual rainfall is between 1000 mm to 1500 mm. Most of the rainfall occurs during the months of July to September. The entire belt experiences gentle to heavy snowfall during the winters.

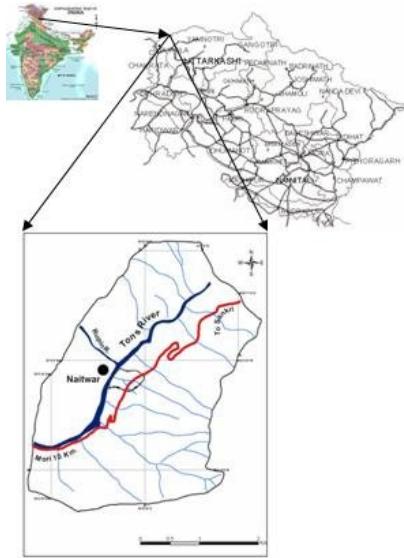


Figure 1: Location map of the study area. Black dotted line on the map outlines the limits of the landslide.

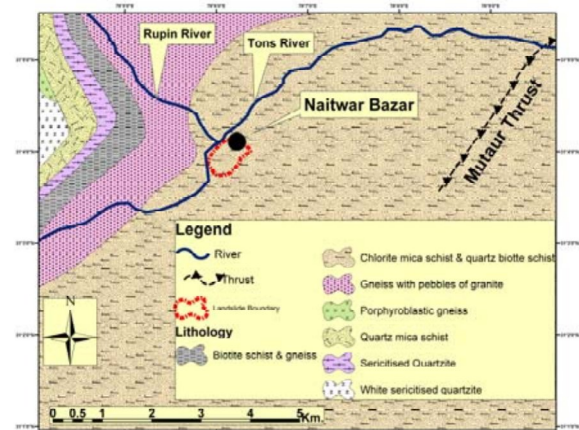


Figure 3: Geological map of Naitwar area (After Jamwal & Siddiqui, 1993).

The area is bounded by Chail thrust in the north and Mutaur thrust in the east. Later is in the close vicinity (about 6 km) of the study area and further east the tectonically fragile and sensitive zone of Main Central thrust truncates all other tectonic units (Jamwal and Siddiqui, 1993).

Geophysical Data Acquisition

A total of six ERT profiles and three gravity profiles were carried out in two different field seasons, one during May – 2005 and June – 2007 repetitively. The locations of the geophysical profiles are given in Figure 4.

ERT Data Acquisition

A multi-electrode Resistivity imaging system, SYSCAL Jr Switch – 72 of IRIS make was used for the present study. A CS 5 portable GPS of Leica make was used for the position location of all the electrodes. A total of six resistivity tomography profiles (Figure 4) were acquired: 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'). Here we include three representative interpreted true model resistivity sections along profiles AA', CC' and FF' (Figures 5, 6 & 7).

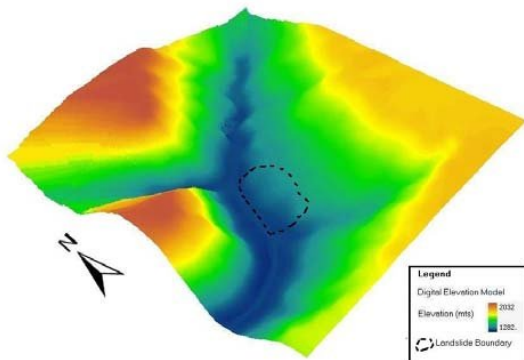


Figure 2: Digital Elevation Model (DEM) of the area with black dashed line demarcating the limit of landslide.

The area under investigation forms a part of Naitwar group of rocks comprising low grade metamorphites and is thrust over the white massive and sericitised quartzite of Garhwal Group, locally named as Sankri formation along a tectonic plane named as Mutaur thrust. At the vicinity of Naitwar bazar landslide the major rock units are Grey chlorite mica schist with greenish tinge and quartz biotite schist with bands of porphyroblastic gneiss and basic intrusives of Kabala formation of Naitwar group (Figure 3). The Chail formation is thrust over the Naitwar group along Chail thrust. This formation extends on the either side of the Rupin River (Jamwal and Siddiqui, 1993).



"HYDERABAD 2008"

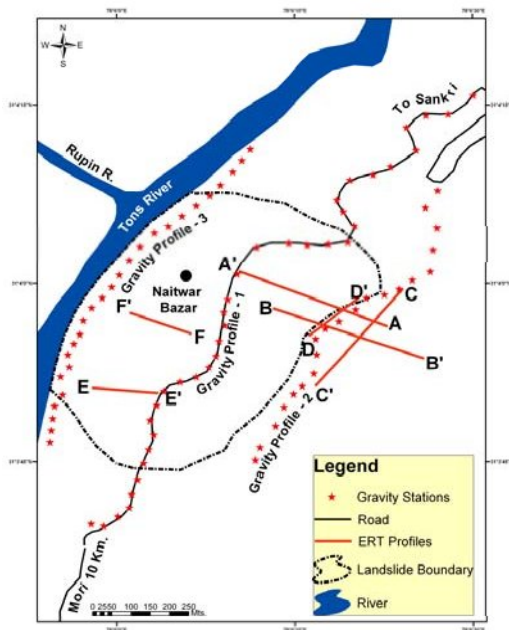


Figure 4: Map showing location of ERT survey lines (AA' to FF') & gravity stations. Black dotted line indicates the extent of active slide zone.

Resistivity data were collected using Wenner Schlumberger (VES) array configuration with electrode spacing of 2 – 5 m. For each profile, more than 1200 measurements were carried out. Topographic corrections and 2D inversion model were performed using the inversion algorithm proposed by Loke and Barker, (1996).

To have uniformity in the interpretation of different true resistivity sections along various profiles, a common colour code has been evolved and adopted for presentation of the 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, which is the basis for the preparation of litho sections from electrical resistivity sections along profiles AA', CC' and FF' (Figure 4).

Resistivity in Ω m.	Rock type
< 30	Clay
30 - 80	Moist Sandy Clay
80 - 200	Wet Sand / Saturated sand
200-500	Highly Weathered Schist
500 - 1000	Semi-Weathered Schist
1000-2000	Moderately -Weathered Schist
2000-3000	Moderately – Fresh Schist
3000-4500	Relatively Fresh Schist
> 4500	Fresh Schist
80 – 120	Fresh Groundwater

Table 1: Adopted table indicating resistivity – lithology conversion.

Gravity Data Acquisition

The gravity survey was carried out in the study area using a CG – 5 gravimeter (Scintrex make) of sensitivity 0.1 mGal. The gravity data were acquired at 74 stations, in three profile lines (Figure 4). A CS 5 portable GPS of Leica make was used for the position location of gravity stations.

Results & Discussions

Electrical Resistivity Tomography

Electrical Resistivity Tomogram -1 along Profile AA'

A layer of relatively low resistivity in the range 200 – 500 Ω m (highly weathered schist) is observed at the lower part of the profile, at a depth range of 5 to 15 m. The same layer is absent in the upper part of the profile, where a relatively higher resistivity range of 500 – 1000 Ω m (semi- weathered schist) and 1000 – 2000 Ω m (moderately weathered schist) zone has been exposed. The profile AA' was conducted at the head scarp zone of the landslide.

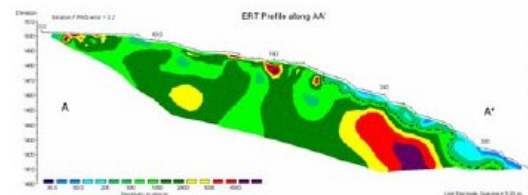


Figure 5 Interpreted ERT section of profile AA' with common colour code with the black dashed line indicating the probable slip surface.

It can be clearly seen from the ERT section that the highly weathered schist exists at the lower portion of landslide and absent in the head scarp zone which has been slithered out during the landslide process. The contact between highly weathered schist and semi – weathered schist appears to be the failure surface, which is demarcated by black dashed line (Figure 5).



Electrical Resistivity Tomogram -2 along Profile CC'

The ERT-2 (Figure 6) along profile CC' (Figure 4) was conducted on the terrace region, adjacent to the present slide zone. This profile vividly describes the depth-wise variation of low to high resistivity zones. Similar to the profile AA', a low resistivity zones was also observed here. Further, the low resistivity zone ($200 \leq \rho \leq 500 \Omega \text{ m}$) is at greater depth than that of AA' and the thickness of this zone is also much higher. The highly weathered schist, which is overlaying the semi-weathered ones situated at a depth range of 20m., may leads to fresh slide in near future.

Already, cracks have been developed in the existing buildings in this region, which supports our findings.

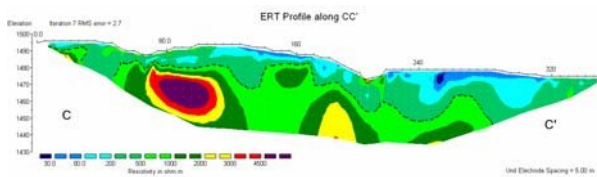


Figure 6: Interpreted ERT section of profile CC' with common colour code with the black dashed line indicating the probable slip surface.

Electrical Resistivity Tomogram -3 along Profile FF'

The ERT-3 (Figure 7) along profile FF' (Figure 4) was conducted near the river. In major part of the ERT, the low resistivity zone ($200 \leq \rho \leq 500 \Omega \text{ m}$) is dominant, but the presence of very low resistivity zone of $80 - 200 \Omega \text{ m}$ (wet sand/saturated sand) is also observed. The presence of low resistivity zone in this range ($80 \leq \rho \leq 200 \Omega \text{ m}$ or $80 \leq \rho \leq 200 \Omega \text{ m}$) possibly infers the presence of groundwater in pockets and may lead to fresh slides in the area. Small pockets of higher resistivity zones at the surface are due to the dislodged material transported from the upper part of slide. The vulnerability of this slope is clearly evident from Figure 6. However, implementation of an ERT with higher electrode separation, immediately after monsoon may be useful for better characterization of this slope.

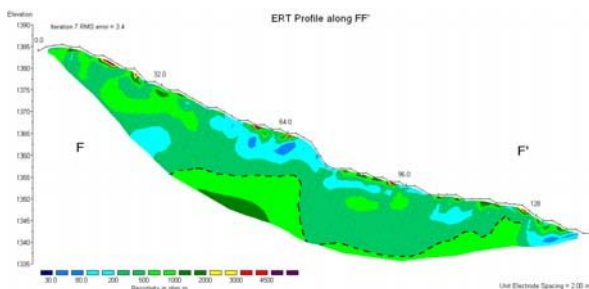


Figure 7: Interpreted ERT section of profile FF' with common colour code with the black dashed line indicating the probable slip surface.

Gravity Results

Density of the fresh rock was obtained from the samples collected from the landslide and All the geo-electrical images (Figures 5, 6 & 7) show the presence of a comparatively low resistivity zone of range $200 - 500 \Omega \text{ m}$ comprising of highly weathered schist. This low resistivity zone may be responsible for respective slope instability. However, in case of profile AA' (Figure 5) absence of this layer in the slid part and exposure of moderately weathered schist in the scarp zone is supportive adjacent area. Accordingly, the density of overburden is set to 2.33 gm/cc with a density contrast of 0.3 gm/cc at hard rock level. The obtained depth to hard rock surface is shown in Figure 8. It can be inferred that the inclination of hard rock surface is almost parallel to the surface topography.

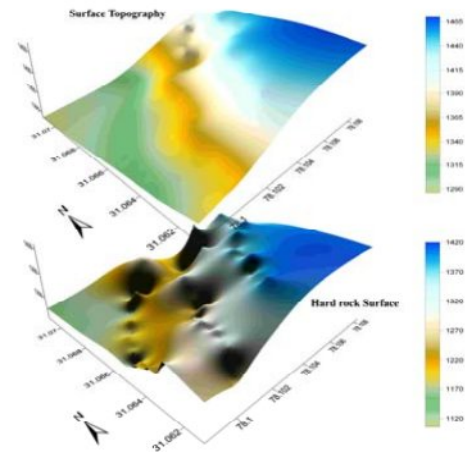


Figure 8: Gravity inferred hard rock surface along with surface topography

for this argument. Further, the same low resistivity zone is comparatively thicker in case of profile CC' & FF' (Figure 6 & 7). In Figures 5, 6 & 7, the contact between the low resistive highly weathered schist and comparatively high resistive moderately weathered schist is marked by black dashed line, which may be acting as the slip surface of Naitwar bazar landslide. 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. The gravity inferred hard rock surface clearly mimics the surface topography, which in turn supports the process of mass movement due to gravity.

Summary & Conclusion

The present study has utilized integrated geophysical methods on an active landslide area in Garhwal Himalayan region. The ERT method combines both 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 to focus the role of electrical imaging in landslide process in situ. Seismic, geo-electric methods are widely used



"HYDERABAD 2008"

for landslide investigations; however our use of gravity survey in landslide investigation is novel.

The achieved results clearly stress the importance of integrated electrical tomography and gravity studies in detailed landslide studies. Repetitive resistivity imaging & gravity surveys may detect the spatial & temporal changes within the landslide body. This will help for better characterization of active landslide processes and facilitate subsequent geotechnical studies for necessary remedial measures, if feasible in areas of complex geology.

References

- Bichler, A., Bobrowsky, P., Best, M., Douma, M., Hunter, J., Calvert, T., and Burns, R., 2004, Three-dimensional mapping of a landslide using multi-geophysical approach: the Quesnel Forks landslide; *Landslide*, 1 (1), 29 – 40.
- Bogoslovsky, V.A. and Ogilvy, A.A., 1977a, Geophysical methods for the investigation of landslides; *Geophysics*, 42, 562–571.
- Bogoslovsky, V.A., Ogilvy, A.A. and Strakhova, N.A., 1977b, Magnetometric and electrometric methods for the investigation of the dynamics of landslide process; *Geophy. Prospect.*, 42, 562–571.
- Colangelo, G., Lapenna, V., Perrone, A., Piscitelli, S. and Telesca, L., 2006, 2D Self Potential tomographies for studying groundwater flows in the Varco d'Izzo landslide (Basilicata, southern Italy); *Eng. Geol.*, 88, 274 – 286.
- Ferrucci, F., Amelio, M., Sorriso-Valvo, M. and Tansi, C., 2000, Seismic prospecting of a slope affected by deep-seated gravitational slope deformation: the Lago Sackung, Calabria, Italy; *Eng. Geol.*, 57, 53 – 64.
- Fraseri, A., Kapllani, L. and Dhima, F., 1998, Geophysical landslide investigation and prediction in the hydrotechnical works; *J. Balkan Geophy. Soc.*, 1 (3), 38 - 43.
- Godio, A. and Bottino, G., 2001, Electrical and electromagnetic investigation for landslide characterization; *Phys. Chem. Earth Pt. C*, 26 (9), 705 – 710.
- Jamwal, J.S. and Siddiqui, M.A., 1993, Delineation of main central thrust across UP – HP border, Uttarkashi District, UP and Shimla District, H.P.; *Geol. Surv. Ind., Rec.*, 126 (8), 255 – 257.
- Lapenna, V., Lorenzo, P., Perrone, A. and Piscitelli, S., 2003, High Resolution Geoelectrical tomographies in the study of Giarrossa landslide (southern Italy); *Bull. Eng. Geol. Env.*, 62, 259 – 268.
- Lapenna, V., Lorenzo, P., Perrone, A., Piscitelli, S., Rizzo, E. and Sdao, F., 2005, 2D electrical resistivity imaging of some complex landslides in the Lucanian Apennine chain, southern Italy; *Geophysics*, 70 (3), B11 – B18.
- Loke, M.H. and Barker, R.D., 1996, Rapid least – squares inversion of apparent resistivity pseudosections by quasi – Newton method; *Geophys. Prospect.*, 44, 131 – 152.
- Mauritsch, J.H., Seiberl, W., Arndt, R., Römer, A., Schneiderbauer, K., and Sendlhofer, G.P., 2000, Geophysical investigations of large landslides in the Carnic Region of southern Austria; *Eng. Geol.*, 56, 373-388.
- Telford, W.M., Geldart, I.P. and Sheriff, R.E., 1990, *Applied Geophysics*; Cambridge University press, UK; pp. 632-701.

Acknowledgements

The authors wish to convey regards to Prof. Sri Niwas and Prof. & Head, Department of Earth Sciences for necessary support in carrying out the geophysical studies. Mr. Suman K. Mondal conveys his sincere thanks to MHRD for the financial support.