Resistivity-IP Surveying for Engineering and Environmental Applications Using Multi-Electrode Equipment

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RESISTIVITY-IP SURVEYING FOR ENGINEERING AND ENVIRONMENTAL APPLICATIONS USING MULTI-ELECTRODE EQUIPMENT

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Introduction

The need of detailed information about the geo-environment is growing as a result of growing cities, infrastructure development and environmental concerns. Due increasingly limited space more tunnels and other underground constructions are needed. Furthermore there is demand for re-use of areas formerly used as waste dumps and contaminating industries. There is also increasing awareness of the need to protect and monitor our ecosystem services, including groundwater resources. The above calls for high quality data with sufficient special resolution, which can only realistically be solved with geophysical data in combination with well targeted in-situ investigations such as drilling, sampling, test pumping etc. Combined resistivity and induced polarisation (IP) imaging creating two dimensional (2D) and three dimensional (3D) images of the subsurface space, can be a powerful tool for this, as is illustrated below.

Method Description

Resistivity and time-domain IP was measured using an ABEM Terrameter LS (Lund System) equipped with 12 measuring channels. This instrument offers several advantages compared to previous generations, improving speed of measurement and data quality. The 12 input channels are based on 24 bit AD-converters with measuring ranges 2.5V, 15V & 1000V, and in addition there are two channels measuring the transmitted current and potential. The constant current transmitter can put out a maximum of 600V, 2.5A or 250W. There is a built-in 64 electrode relay switch, and a GPS receiver. In the examples presented here multiple gradient array was used (Dahlin and Zhou 2006). In addition potentials were measured outside the transmitter electrode pair (bipole-dipole array) in order to increase the sensitivity towards the ends of the electrode layout, and we may thus call it an expanded i.e. multiple gradient array. Res2dinv or Res3dinv with the L1-norm (robust) inversion norm was used for creating the models presented here (Loke et al. 2003).

Example Landslide Risk Due to Quick Clay

In parts of Sweden, Norway and Canada the occurrence of so called quick clay constitutes serious landslide hazards. Quick clay is formed by clay that was deposited in a marine saline environment, which has later been leached by circulating groundwater and deprived of its salt content. As salt is removed the clay can be come unstable and liquidise due to a small disturbance. Previous research has shown that resistivity mapping can be used for separation of saline soil volumes that are stable, from volumes that may be leached and quick (e.g. Rankka et al. 2004; Lundström et al 2009). Dry crusts and thin weathered zones at top have high resistivity but are non-quick. Soils with less clay content will have higher resistivity without being quick. Supplement is thus needed from geotechnical investigations, but on the other hand a resistivity investigation is an excellent basis for designing a geotechnical drilling / sounding program.

A recent example is a resistivity-IP survey that was carried out in an area close to Göta Älv in 2010. During 5 field days 8 lines with a combined length of 3800 m and comprising over 26 000 resistivity-IP data points were measured. Inversion gave consistent models with low model residuals (1-2% for resistivity, 3-7% for IP). A fence diagram that gives an overview of the inverted resistivity models is shown in Figure 1. Preliminary evaluation of the results shows that there is good agreement between the resistivity models and geotechnical sounding data. Thus, the lowest resistivities show non-quick saline clay, intermediate resistivity is possible quick clay but may also be other soil types, whereas the highest resistivities are due to crystalline rock.

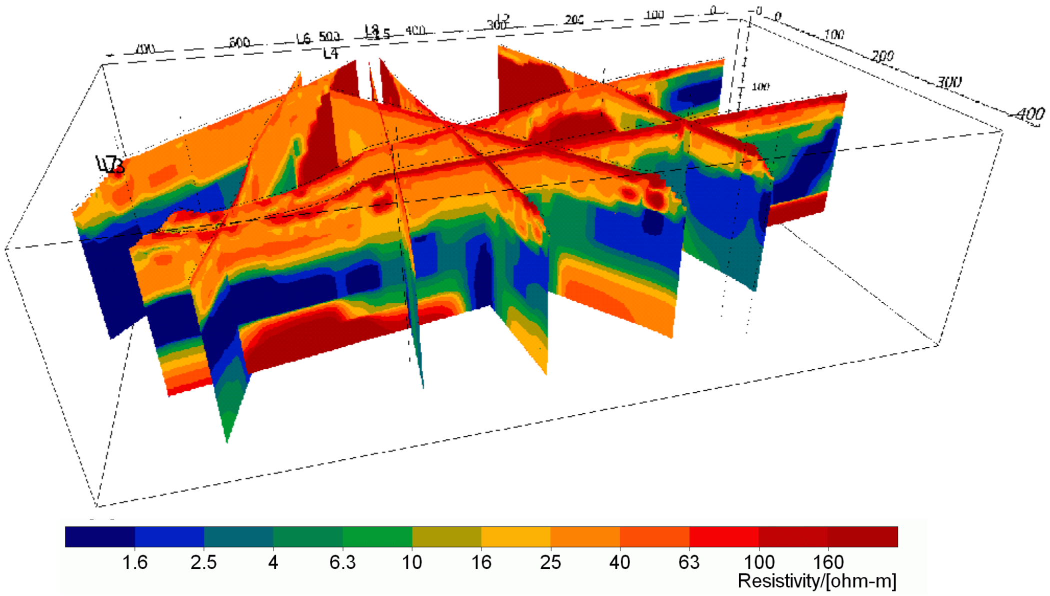

Figure 1. Resistivity results from quick clay delineation at Göta Älv.

Example Waste Characterisation

Buried waste in old landfills is an increasing problem as cities expand and grow into areas with former waste deposits. In order to be able to manage and as far as possible reclaim land in such areas, better tools are needed for mapping and characterisation of buried waste and contaminated land. Combined resistivity-IP surveying has shown great potential for this (e.g. Dahlin et al 2010).

As part of an on-going research project[3] a 3D survey was carried out over part of an existing landfill, using 300 m long layouts with 5 m electrode take-out spacing. A total of 11 lines 300-330 m long spaced 10 m were measured in one field week, resulting in 17680 resistivity-IP data points on a total of 3330 m of profile. Data were inverted with Res2dinv and Res3dinv using L1-norm (robust) inversion. The model residuals were in the range 1-2% (resistivity), 7-10% (IP) for the 2D inversion.

An example of preliminary results is shown in Figure 2. The volumes with high normalised chargeability are interpreted to consist of mixed waste or leakage contamination, whereas low chargeability volumes are interpreted as soil cover on top of the waste, soil barriers between waste cells and sedimentary rock below the waste respectively. Parts of the waste that are not covered by soil are clearly visible as high chargeability at the surface. High chargeability in the bottom part of the model may possibly be caused by precipitation in connection with contaminant migration.

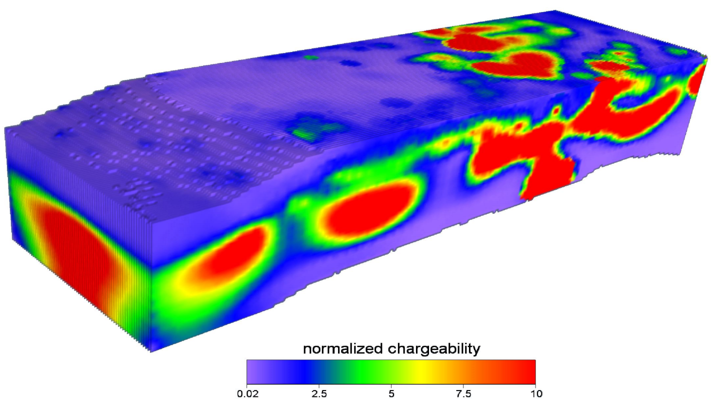

Figure 2. Normalised IP model based on 3D inversion of data from Filborna waste deposit.

[3] MaLaGa (Mapping of landfill structures and gas migration based on geophysical measurements), see http://malagageophysics.blogspot.com/ for information.

Example Embankment Dam Survey / Monitoring

Resistivity monitoring can be a powerful concept for tracing migration of fluids and ions (e.g. Sjödahl et al. 2007; Sjödahl et al. 2009). A short term monitoring investigation was carried out on a small embankment dam with the purpose to identify leakage paths (Sjödahl et al. 2011). Measurements started with the reservoir water at a lower level, and were repeated after the reservoir level had been raised by 0.55m. The survey line was 63 m long with electrodes at 1 m spacing. Since a large part of the line was paved holes were drilled through the pavement, and the holes were filled with granulated clay and water to provide electrode contact. Resistivity measuring was repeated 13 times in total, and combined resistivity-IP measuring repeated 2 times. The total time for the survey was less than two days form the start to end of measurements, during which a total of 41 910 data points were measured. Remote control via mobile internet modem was used to enable measurement control away from the site. Res2dinv time-lapse inversion using L1-norm gave model residuals in the range 2 - 4 %.

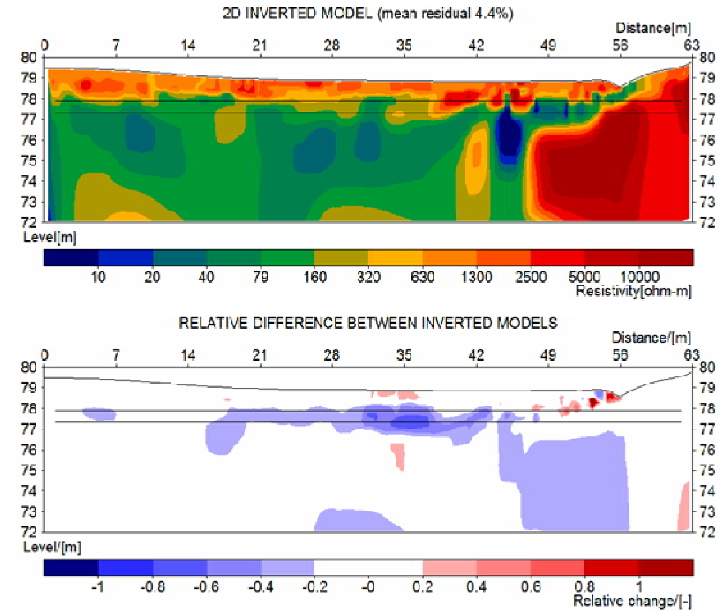

Figure 3. Example results from embankment dam study; a) inverted resistivity model, b) change in resistivity between first and last time-step.

Example results are presented in Figure 3, where the two horizontal lines show the initial reservoir water level and the level after raising the water level. The difference section clearly outlines zones of decreasing resistivity in this level interval that can be interpreted as the major water leakage paths. The zones of decrease at larger depth in the section are probably due to 3D effects, whereas the small zones of increase in resistivity may be due to drying out of soil that was not protected by pavement during the rains preceding this survey.

Summary / Conclusions

The experiences illustrated by the above examples can be summarised as:

- There is large potential for resistivity-IP imaging in environmental and engineering applications.
- Multi-electrode multi-channel data acquisition is time and cost efficient.
- Time-domain IP data acquisition is fast, and provides useful data if site conditions permit.
- Better inversion software is needed for full interpretation of IP data.
- There is more to learn about applicability and interpretation of IP data.
- Migration of water and / or pollutants can be traced with time-lapse studies / monitoring.

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СЕКЦИЯ 4

РУДНАЯ ЭЛЕКТРОРАЗВЕДКА