Applying Syscal-Pro resistivity-meter in fast measurement mode to soil investigation

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Summary

The paper deals with geophysical aspects of studying soils by resistivity method.

Electrical resistivity measurements have recently come to use in field experiments to explore soil structure. Rapid resistivity-meters like 10-chanels Syscal-Pro (Iris Instruments) are able to record hundreds of measurements per minute. Such units open new possibilities for soil investigation.

The authors fitted Syscal-Pro for soil exploration. All 96 electrodes were fixed in 8 plastic slabs with 10 cm inter-electrode spacing. Fast and exact setup of array is thus provided. Three different types of measurements were implemented: 2D and 3D resistivity imaging and the infiltration monitoring. The following geophysical results were obtained:

- Using Syscal-Pro in fast measurement mode allows rapid data gathering with good quality.
- Small electrode spacing, quite common in soil exploration, requires special electrode design.
- Pole-dipole array occurred to be highly effective as it provides the widest possible spacing range.
- Drilling, made to verify 2D resistivity imaging results, unveiled that the equivalence effect is likely to cause boundary depth variations due to sharp resistivity changes in overburden.
- Electrode charge-up effect becomes evident in fast measurements mode. Measurement sequence should be thus optimized in order to increase the time gap between measurements using certain electrode.

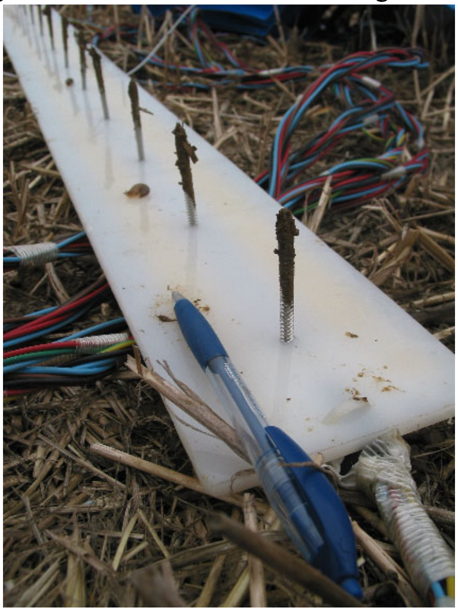

Fig. 1. Plastic slab with electrodes.

Introduction

For several years, electrical resistivity has been used in field experiments to both describe small variations in soil bulk density or modifications of the soil water content (Michot et al, 2003; Besson et al., 2004). 2D resistivity imaging can be applied to soil exploration as soil's resistivity varies according to soil's type and conditions.

Exploring very shallow depths poses special requirements to electrodes. Their size should be several times less than inter-electrode spacing. Nether the less, electrodes should still have good contact with the ground and provide switching to the streamer.

Rapid property changes are specific for soils either. It means that surveying at long representative observation lines is the only way to determine soil's integral properties.

Fast multi-channel electrical prospecting equipment allowed new approach to soil exploration.

Fig 2. General view on investigated site.

Fitting electrodes and streamers

Conventional electrodes and streamers, supposing inter-electrode spacing of 1 m at least, cannot be used for small spacings. Because of that special electrodes and streamers were created (Fig. 1). Electrodes were made of stainless screws which were firmly fixed at hard plastic slabs at 10 cm spacing. The trim-box was used for connection to Syscal-Pro unit (96 electrodes were divided into 8 groups, 12 electrodes in each). Transportation and deploying was thus simplified and allowed to implement 3D resistivity imaging with an 8 x 12 grid.

Field technique

Two-sided pole-dipole array was used, providing the greatest AO spacing of 6.65 m with the total array length of 9.5 m. Three lengths of MN line was used 0.1, 0.5 and 1.5 m. This type array has some more advantages as follows:

- It can be easily adapted for parallel, multi-channel measurements.
- Comparing forward and reverse arrays data provides means for data control.
- Great number of independent measurements results in reliable 2D iversion (Dahlin and Zhou, 2004).

The measurement with pole-dipole array allows to receive the resistivity data for the depth range from 0.1 up to 2.2 m.

The use of a Syscal Pro resistivity-meter developed by IRIS-Instruments allows to reduce the acquisition time. This fast resistivity-meter has ten reception dipoles available to carry out some measurements with high productivity in the field. The time saving is based on a quick mode with a pulse duration of 240 ms for the injected current constituted by one positive pulse and one negative pulse only. To take full benefits of the ten channels sequences (set of combinations of quadrupole) are optimized. Parallel measurements require the same current injection dipole but also a common point for the successive potential measurement dipoles. With such a resistivity-meter and a completely optimized sequence, it is possible to acquire approximately 600 apparent resistivity points per minute

2D survey results

Experiments were implemented in a haplic luvisol developed in cryoturbated limestone in Beauce, France (long.:1°46'22'' Est ; lat.: 48°22'38'' Nord) Moeys et al., 2006]. The exploration site was about 1 km long. 4 observation lines, about 40 m each, at different soil types were surveyed at the site. About 10000 values of apparent resistivity were obtained at each line. Measurement at a single line, including array deployment and removal, took about 2 hours, measurements itself took about half of that time. Using slower measurement mode would decrease the productivity significantly.

The lines' position and result of 2D resistivity imaging dada inversion are presented on fig. 3.

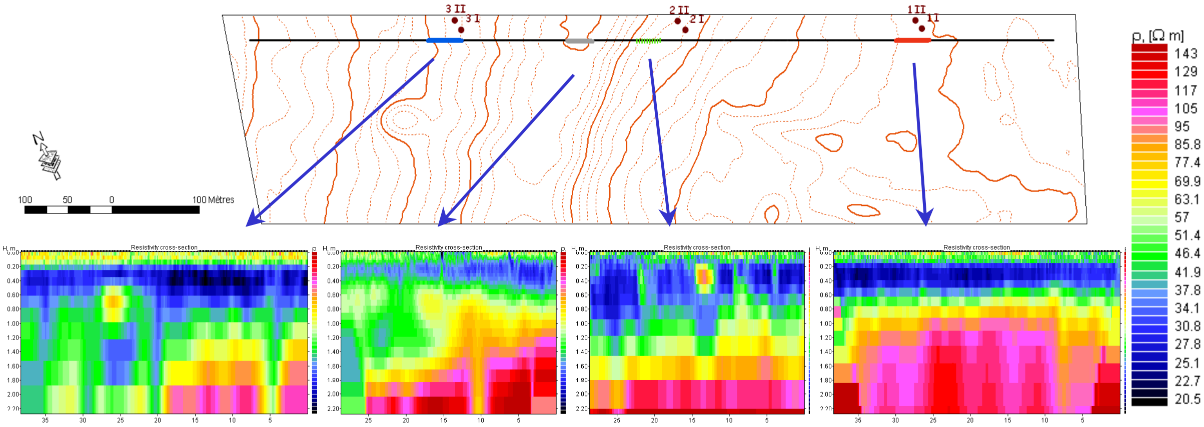

Fig. 3. Map of the facts, profiles position and results of 2D inversion by Res2dinv. The depth of investigation is 2.2 m for all lines.

The soil in general is organised in 3 layers: a cryoturbated calcareous zone (electrical resistivity: 80-150 Ohm.m) below 60 cm, a clay-loamy horizon (electrical resistivity: 20 to 40 Ohm.m) from 20 to 60 cm depth, a ploughed loamy-clay horizon (dispersed values of electrical resistivity with a median value of 50 Ohm.m) from 0 to 20 cm depth.

Properties' variations are obvious at the base of the cross-section in cryoturbated zone. The clay-loamy horizon is more consistent with smooth changes of resistivity. Electrical prospecting results were verified by hand drilling to the top of limestones, which underlay soils. It was hard to distinguish the hard bedrock from great limestone fragments inside eroded zone.

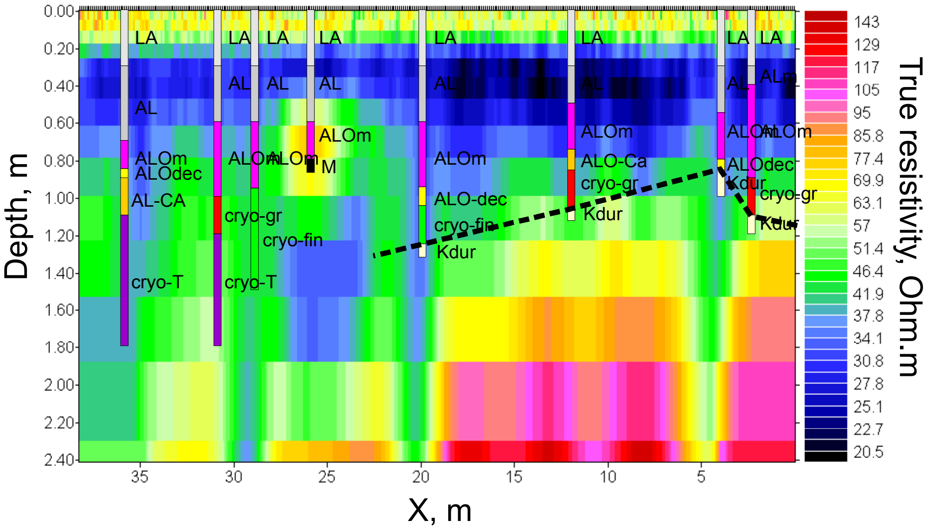

Fig. 4. Geoelectrical cross-section and drilling results. Dashed line denotes the top of bedrock limestones.

The drilling results are shown together with the geoelectrical cross-section (Fig. 4). In the left part of line the limestones are situated deeper than 1.8 m (they did not occur at that depth, the greatest possible for portable drilling equipment used). In the right part good correlation of the top of resistive layer with the top of limestones is observed everywhere, besides two zones (X coordinates 20 and 5 m), where the resistor sinks. Core analysis unveiled very argillous (conductive) layer (ALO-dec) in boreholes drilled at those places. It is this thin layer of high contrast, that results in wrong limestones depth estimations at those places. This effect is shown on fig. 5 with observed apparent resistivity curve and two equivalent 1D modeling results.

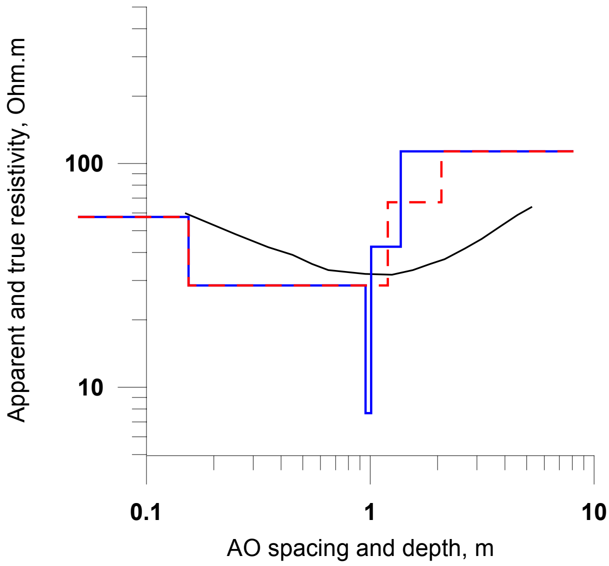

Fig. 5. Observed apparent resistivity curve and two equivalent 1D model.

Electrode charging effects

Using fast approaches always arises the question about accuracy of measurements. The simplest way of the accuracy estimation is repeated measurements. During the field work the monitoring experiment was carry up with measurement each 5 minutes to estimate water distribution after irrigation. The pedological results of this experiment are beside of the present papers but geophysical analyze of gathered data allows to estimate the accuracy of the survey with fast approach.

On Fig. 8 comparing two pseudo section for forward pole-dipole arrays is shown. The difference for short spacing (less 0.5 m) is the indication of infiltration process. The mean difference on the greater spacing is less than 1%. It prove the good accuracy of fast measurements for soil investigations. Let us look on the same data set with reverse pole-dipole.

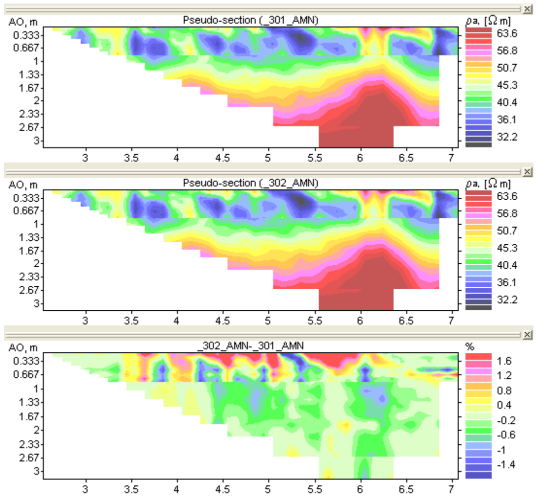

Fig. 8. Apparent resistivity pseudo-sections for forward pole-dipole array at two times and the difference between them.

Three examples of those data with reverse pole-dipole array are shown at Fig. 9. We clearly see the bad points for two data set. The cross-section in the middle was gained with 96 electrodes. In this case measurements took more time that two others, which were gathered with 48 electrodes only. This stable effect can be explained only by electrode charging-up, i.e. polarization, occurring due to applying electric current, had not decay during the time gap between using a certain electrode in measurements (Dahlin, 2000).It is evident that simple change of the quadripoles' order could help to avoid this effect and to improve the quality of measurements.

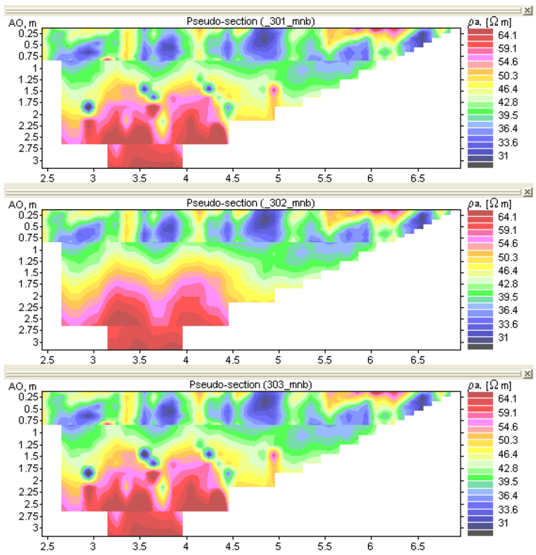

Fig. 9. Apparent resistivity pseudo-sections for reverse pole-dipole array at three times.

Conclusion

Fast resistivity-meters can be successful applied to soil investigations after the adaptations of electrodes and the optimization of quadripoles' sequence. Pole-dipole array helps to expand the spacing range and to analyze the data.

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