Novel electrode design for non-destructive resistivity measurement on material in geotechnical standard sample cylinders

T. Dahlin[1], M. Lumetzberger[1], P. Hedblom[1], S. Rejkjær[1], P. Olsson[2]

[1] Lund University; [2] WSP

Summary

We present a novel design of an electrode arrangement for measurement of the resistivity of soil samples contained in a sample cylinder used in standard geotechnical site investigations in Sweden. The objective is to make it possible to measure the resistivity of the same samples that are to be used for mechanical tests, without disturbing the samples in order to get unbiased mechanical test data. A design with four piece-of- pie shaped electrodes integrated in the lids in each end of the sample has been tested and evaluated. Temperature sensors are embedded in the electrode lids to allow temperature compensation of the measured data.

Alternative electrode designs were modelled numerically with the finite element method (FEM) prior to the prototype manufacturing. Measurement tests with water filled sample cylinders show that stacking and reciprocal errors can be kept below 1% provided that suitable measurement settings and sequences are used. The geometrical factors depends on the distance between the electrodes in each end of the cylinder, i.e. varies with the length of the sample, and must be determined experimentally or via FEM modelling.

Novel electrode design for non-destructive resistivity measurement on material in geotechnical standard sample cylinders

Introduction

We present a novel design of an electrode arrangement for measurement of the resistivity of soil samples contained in a sample cylinder (50 mm inner diameter and 170 mm length) used in standard geotechnical site investigations in Sweden (SGF 2009). The same type of sample cylinder is used for laboratory testing of different binder recipes in connection with soil stabilisation where research is also ongoing regarding the use of electrical measurements for quality control of stabilised soil (Olsson et al 2019). To make it possible to measure the resistivity of the same samples that are to be used for mechanical tests, and get unbiased mechanical test data, it is critical not to disturb the samples by pushing electrodes into them. Furthermore, it would be an advantage to have a measurement concept with an electrode design that allows resistivity measurement of an arbitrary soil sample taken for geotechnical analyses. This could pave the way for resistivity measurement on samples taken in various projects in order to build a database of resistivities of soils that can be linked to their geotechnical properties. Traditionally, resistivity measurements in geotechnical laboratories are made by packing the soils samples in square shaped soil boxes, with current transmission between metal plates in each end of the sample and potential electrode that penetrate through it (ASTM 2005).

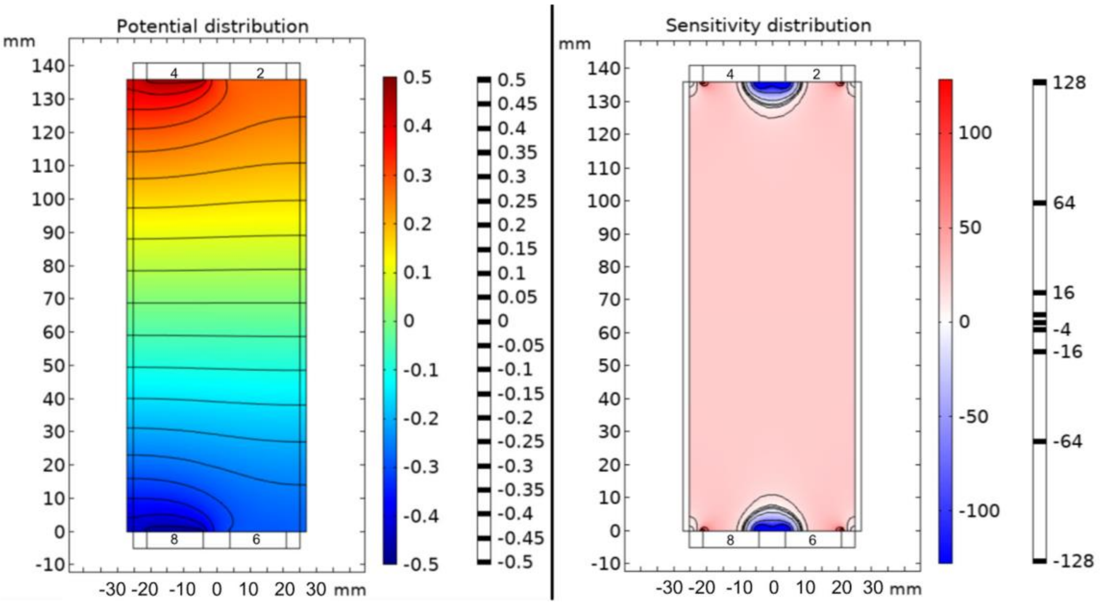


Figure 1 Example of FEM modeling results showing solution for potential field (left) and sensitivity distribution (right) for current and potential electrodes shown in Figure 3; Std3.

The concept of determining the resistivity of a cylindrical soil sample is similar to that of a piece of wire, where current is injected and potential is measured in the same points but via separate cables. For soil samples the same measurement geometry would have been ideal, but the electrode contact resistance which cannot be determined in practice can result in large errors. This means that a modified concept with separated current and potential electrodes needs to be adopted. We have tested a design with four separate electrodes in each end of the sample, which are used as current and potential electrodes in different permutations. By doing so, the problem of contact resistance bias is overcome, and it opens up possibilities to do reciprocal measurements as well as other quality assessments related to sample heterogeneity. Electrodes shaped like pieces of pie were chosen, as that maximises the contact area which minimises contact resistance and thus the required voltage to drive a current through the sample. Furthermore, this leads to an almost homogeneous current field through the cylinder for homogeneous media if all electrodes are combined as current electrodes, which allows comparison with measurements using potential electrodes placed on the sample cylinder as reference for evaluation purposes.

Synthetic modelling

Numerical modelling of the electrode design with the finite element method (FEM) was carried out in Comsol Multiphysics (v. 5.5). Through the synthetic modelling, several different electrode designs were evaluated. In particular two designs based on four electrodes in each lid but with different electrode shape (pie pieces and circular) and one design with only two electrodes in each lid (concentric rings). For brevity, only the results for piece-of-pie shaped electrodes are shown. Based on this geometry, discretization, material properties and boundary conditions, steady-state solutions were computed for all possible current electrode combinations, see example of one combination in Figure 1. The FEM modelling results were used for numerical estimates of the geometric factors (K) for all possible quadrupoles based on sampling of the model potential and current at the relevant electrodes.

Prototype design

We use a design with 3D printed sample cylinder lids (Figure 2), where the surface of the 3D printed parts is waterproofed. The electrodes are made from stainless steel and laser cut from a 5 mm thick plate, which are glued in place before the interior is sealed by a potting agent to secure water tightness and electrical isolation of the connections to the electrodes. Since the resistivity is strongly temperature dependent, and the binder reaction results in heating of the sample, temperature measurement in parallel with the resistivity measurement is essential. Hence Pt1000 temperature sensors are integrated in the electrode lids, placed in between the electrodes, for connection to temperature loggers.

Figure 2 *Photographs showing electrode lid design for the piece-of-pie shaped electrodes together with sample cylinder with standard lids (left), and a group of lab samples prepared for measurements (right).*

Laboratory tests

The physical electrode design was evaluated by measuring on the sample holder filled with tap water and conductivity reference fluids with an ABEM Terrameter LS2 instrument. In addition, the test measurements were made using a sample cylinder with holes drilled for potential electrodes, so that the potential difference can be measured in between the current electrodes in the traditional way for reference.

We measured different electrode array combinations between the end electrodes (Figure 3), for example cross-lid current transmission with C1 and C2 above each other, and P1 and P2 in a similar fashion on the other electrodes (Figure 3; Std3). All arrays were rotated around the clock, which results in data that allows statistical evaluation as well as reciprocal analyses of the data quality. Furthermore, measurements were for evaluation purposes taken between the reference electrodes on the side of the sample cylinder while transmitting current between all four electrodes in each end of the cylinder wired together (Figure 3; Ref1). In this case a current and potential field that is essentially identical to that of a single plate electrode in each end of the cylinder is generated, so that this can be regarded as reference measurements with analytic geometric factor based on the cross section area and the distance between the potential electrodes. Reciprocal measurements were also taken for the reference electrodes using single pairs of piece-of-cake electrode (Figure 3; Ref2).

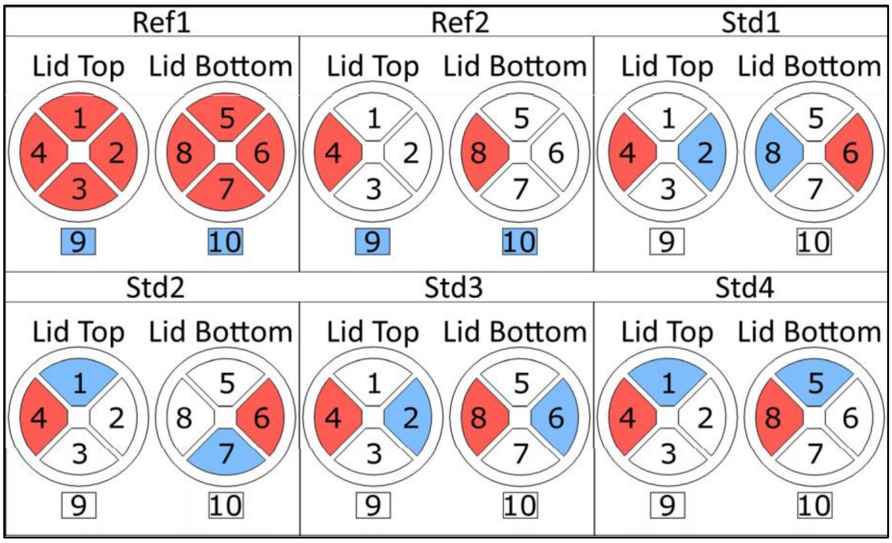
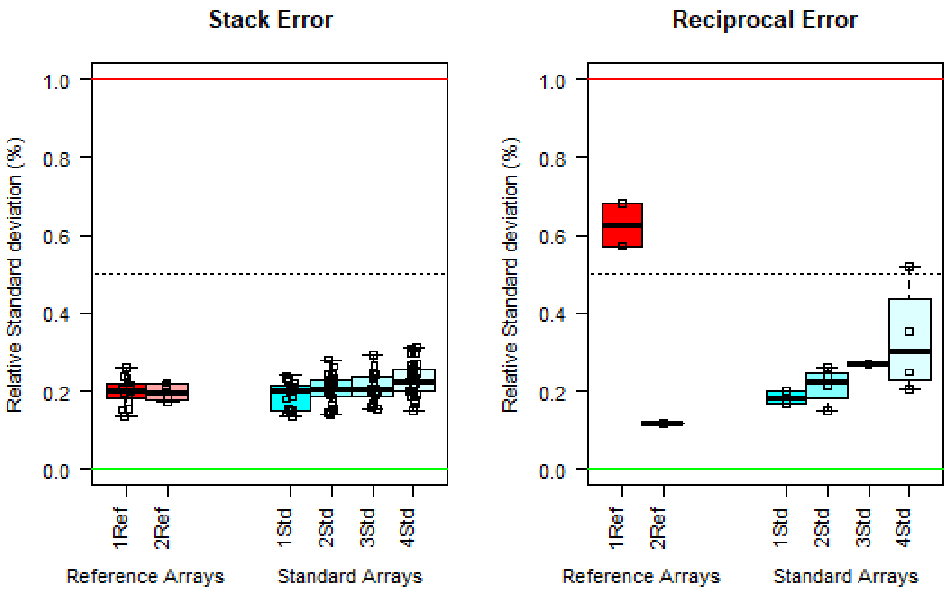


Figure 3 *Measured electrode array combinations with red current and blue potential electrodes.*

Results

Measurement tests with the sample container filled with tap water as well as conductivity reference fluids have given good quality data but have also revealed that the measurement process and instrument setup need to be carefully designed. It is essential not to transmit too much current in order to avoid electrochemical processes at the surface of the current electrodes that produce gas and result in corrosion of the electrodes, which will in turn lead to deterioration of the data quality. Furthermore, the measurement sequence is important in order to reduce electrode charge up effects in the measured data (Dahlin 2000). Careful orientation of the electrode lids relative to each other, and as well as documentation of the distance between them, is also paramount for the accuracy of the estimated geometric factors. The results (Figure 4) show that data stacking variability and the reciprocal errors can be kept under 1%.

The geometrical factors depend on the setup geometry, for example the relative lid rotation and on the distance between the electrodes in each end of the cylinder. This means that the geometric factors will vary with the length of the sample and must be determined experimentally or via FEM modelling. By using the data from the reference electrodes (Figure 3; Std1) to first determine the resistivity of water in the sample cylinder based on analytical geometric factor can the other geometric factors be determined experimentally. Another option is to measure on a standard solution for calibration of conductivity meters but this also requires correction of temperature effects. At the time of writing, assessment is ongoing on the different methods for estimating the geometric factors.



.

Figure 4 *Result of test measurements with sample container filled with tap water. Abbreviations on the x-axis refers to labels in Figure 3*

Conclusions

We have developed electrode lids with several integrated electrodes that makes it possible to measure the resistivity of soil samples in a standard sample cylinder used for geotechnical testing. This opens possibilities to measure on the same soil samples that are used for geotechnical laboratory tests. The electrode design allows data quality assessment via reciprocal measurements, which shows that data of good measurement technical quality can be produced provided that the measurement setup is designed properly. Other possibilities for quality assessment, for example related to sample heterogeneity are still to be addressed.

Acknowledgements

The work was carried out within the framework of the InfraSweden2030 project "ASSERT - Assessment of soil stabilisation using electrical resistivity tomography" (Vinnova project id 2018-00649) which is funded by Vinnova, Formas, Energimyndigheten, SBUF, Trafikverket, NCC and PEAB. We would like to thank Arbias Zejnullahu for his excellent work and patience in connection with the CAD design of the electrode lids.

References

ASTM (2005) *Standard test method for measurement of soil resistivity using the two-electrode soil box method*. American Society for Testing and Materials, G187–05.

Dahlin, T. (2000) Electrode charge-up effects in DC resistivity data acquisition using multi electrode arrays, *Geophysical Prospecting,* 48(1), 181-187.

Olsson, P.-I., Rejkjær, S., Dahlin, T., (2019) Field-Scale Quality Control of Lime-Cement Pillar in Conductive Clay Using Electrical Resistivity Tomography, in: *Procs. Near Surface Geoscience 2019*, We_INFRA_P25, 5p.

SGF (2009) *Metodbeskrivning för provtagning med standardkolvprovtagare Ostörd provtagning i finkornig jord*, Swedish Geotechnical Society, SGF Rapport 1:2009, 16p.