PhD Thesis Summary

Two-dimensional imaging properties of DC geoelectric arrays using numerical and analogue modelling

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[17] K. Szokoli, S. Szalai, and A. Novák. Increasing the depth of detectability of ERT measurements. *Near Surface Geoscience: 19th European Meeting of Environmental and Engineering Geophysics*, 2013.

1. Introduction and research objectives

The so-called vertical electrical sounding (as a geoelectric technique) was elaborated in the early 1900s, in order to get information about the layered (or one-dimensional, 1D) subsurface. Although more than one hundred geoelectric arrays are known, only 5-6 of them are commonly applied in practice: the ones whose field implementation and data processing are both simple. We call these arrays **traditional arrays**. Although for the last decades the application of geoelectric arrays has been extended to 2-, and 3-dimensional (2D and 3D) geological tasks, the arsenal of geoelectric arrays in practice has remained the same. At the same time there is a growing demand to maximize all available information from the measurements about the subsurface.

About two decades ago, a new research direction was initiated at the Geodetic and Geophysical Institute of the Hungarian Academy of Science: studying arrays, supposed to be especially sensitive to multidimensional variations.

The γ**-type arrays**, investigated by the candidate, are special arrays, applicable in 2D electrical resistivity tomography (ERT) measurements, due to their linearly configured feature. The studied arrays are quasi-null ones, which means that their response on the surface of a homogeneous half-space is close-to-zero. They have not become popular for various reasons, among others because of their data processing complexity.

The candidate investigated two-dimensional imaging properties of the γ-type- and of the traditional arrays using numerical and analogue modelling techniques. The investigation focussed on the **depth of detectability** and **horizontal resolution** of the various geoelectric configurations for vertical plate and prism models.

The candidate established close-to-reality conditions for the analogue modelling. As for analogue modelling, the candidate's objectives were to investigate the applicability of the γ-type arrays in noisy environment and to compare their imaging properties with those of traditional arrays for the same numerical and analogue models.

2. Short description of the investigation

The candidate carried out the investigations, both the **analogue and numerical modelling** with the most frequently used traditional arrays: Wenner-Schlumberger (W-Sch), Wenner-α (W-α), Wenner-β (W-β), Dipole-Dipole (Dp-Dp), Pole-Dipole (P-Dp), the four-electrode optimized Stummer (St), γ_{11n} (n=1-7), γ_{q0} and the γ_{313} arrays.

Thesis 1 is a general conclusion, valid both for analogue and numerical investigations, independent of the studied models.

In the numerical study of the **depth of detectability** (Thesis 2) the candidate investigated a conductive vertical plate model, situated at depths 4-14 times larger than its thickness.

In the numerical investigation of the **horizontal resolution** (Thesis 3) the separability of parallel thin plates was studied. Each of the plates were thin, vertical, and electrically conductive. The distance between them were respectively 2.5 and 5 times larger than their common depth.

The candidate added normal distribution random noise of 3 per cent to the calculated apparent resistivity values in both numerical investigations.

In Thesis 4, the results of numerical modelling (Theses 2 and 3) are confirmed by the analogue modelling. For the analogue modelling special **close-to-reality conditions were established**. The half-space was modelled by using wet sand, with resistivity inhomogeneities, due to the inhomogeneous water content. Electrode polarization also occurred. In the analogue modelling the conductive vertical plate model was represented by a graphite plate.

Thesis 5 is based on a phenomenon observed in the depth of detectability analysis of the graphite plate model using a high el-

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[9] S. Szalai and K. Szokoli. Better than the optimised traditional ERT array - The γ_{11n} arrays. *Near Surface Geoscience: 19th European Meeting of Environmental and Engineering Geophysics*, 2013.

[10] S. Szalai and K. Szokoli. New arrays in the geoelectric prospection. *7th Congress of the Balkan Geophysical Society*, 2013.

[11] S. Szalai, K. Szokoli, A. Novák, M. Varga, and L. Szarka. Classification and basic parameters of geoelectric arrays. *6th Congress of the Balkan Geophysical Society*, 2011.

[12] S. Szalai, K. Szokoli, E. Prácser, A. Frigy, and V. Wesztergom. The first inversion results with the γ_{11n} configuration. *77th EAGE Conference & Exhibition*, 2015.

[13] S. Szalai, K. Szokoli, M. Varga, A. Novák, and L. Szarka. From the theoretical results of the research project 'non-conventional geoelectric arrays'. *73rd European Association of Geoscientists and Engineers Conference and Exhibition*, 6, 2011.

[14] S. Szalai, K. Szokoli, M. Varga, A. Novák, and L. Szarka. Several results from our near-surface geoelectric investigations. *6th Congress of the Balkan Geophysical Society*, 2011.

[15] S. Szalai, M. Varga, A. Novák, K. Szokoli, and L. Szarka. From the practical results of the research project 'non-conventional geoelectric arrays'. *73rd European Association of Geoscientists and Engineers Conference and Exhibition*, 6, 2011.

[16] S. Szalai, V. Wesztergom, K. Szokoli, A. Frigy, and E. Prácser. Field applicability of the γ_{11n} configuration. *8th Congress of the Balkan Geophysical Society*, 2015.

Significant PhD-related publications

[1] S. Szalai, A. Koppán, K. Szokoli, and L. Szarka. Geoelectric imaging properties of traditional arrays and of the optimized Stummer configuration. *Near Surface Geophysics*, 11(1):51–62, 2013.

[2] S. Szalai, I. Lemperger, M. Metwaly, Á. Kis, V. Wesztergom, K. Szokoli, and A. Novák. Multiplication of the depth of detectability using γ_{11n} arrays. *Journal of Applied Geophysics*, 107:195–206, 2014.

[3] S. Szalai, I. Lemperger, M. Metwaly, Á. Kis, V. Wesztergom, K. Szokoli, and A. Novák. Increasing the effectiveness of electrical resistivity tomography using γ_{11n} configurations. *Geophysical Prospecting*, 63(2):508–524, 2015.

[4] S. Szalai, K. Szokoli, M. Metwaly, Z. Gribovszki, and E. Prácser. Prediction of the location of future rupture surfaces of a slowly moving loess landslide by electrical resistivity tomography. *Geophysical Prospecting*, 65(2):596–616, 2017.

[5] K. Szokoli, L. Szarka, M. Metwaly, J. Kalmár, E Prácser, and S Szalai. Characterisation of a landslide by its fracture system using Electric Resistivity Tomography and Pressure Probe methods. *Acta Geodaetica et Geophysica*, 2017.

PhD-related presentations

[6] S. Szalai, A. Novák, and K. Szokoli. Seeing deeper by ERT measurements. *7th Congress of the Balkan Geophysical Society*, 2013.

[7] S. Szalai, A. Novák, K. Szokoli, and E. Nádasi. New ERT arrays to increase the depth of detectability. *22nd European Meeting of Environmental and Engineering Geophysics, Near Surface Geoscience*, 2016.

ectrical conductivity cylinder model embedded in a less conductive medium. It was investigated at depths in the range of diameter of the model.

In the analogue investigation of the **depth of detectability**, the candidate studied a graphite plate in depths 4-14 times its thickness. In the analogue study of the **horizontal resolution** (Theses 4 and 5) the candidate investigated the separability of three parallel, individually 0.5 cm thick graphite plates where horizontal distances were 2.5 and 5 times their depth, respectively.

Thesis 6 relates to every analogue investigation, independently from the applied models.

3. Original Scientific results

Thesis 1

The candidate showed that a **joint application of the γ_{11n} (n=2-7) arrays and their mirrored versions (γ_{n11} (n=2-7)) displays the investigated model more precisely** than any single application of the original γ_{11n} (n=2-7) arrays. There are less disturbing pseudoanomalies on the inverted resistivity sections.

Thesis 2

The candidate determined the **depths of detectability** of the traditional arrays and the γ_{11n} (n=2-7) arrays by **numerical modelling** for a conductive vertical plate model and defined the detectability order (with ascending depth of detectability values):

- **α-type (W-Sch, W-α) arrays**
- **β-type (P-Dp, Dp-Dp, W-β) arrays**
- **γ_{11n} (n=2-7) arrays**

Thesis 3

The **numerical study of the horizontal resolution** showed that the α-type arrays are not at all able to separate the plate models from each other. The β-type- and the optimized (Stummer) arrays, the γ_{111} and the γ_{112} arrays are able separate only the distant plate model. At the same time, most γ-type arrays are able to separate all three plate models from each other.

Thesis 4

The results of **the depth of detectability and horizontal resolution investigations were confirmed by analogue model measurements**. The numerical investigation was carried out for traditional and γ_{11n} (n=2-7) arrays, and for a conductive vertical plate model. It was also shown that the noise does not prohibit measurements by using such non-conventional arrays.

Thesis 5

In case of vertical plate and cylinder models, the candidate showed that **better localization and better model imaging accuracy** can be reached by using the γ_{11n} (n=2-7) arrays, than by using the traditional ones. This statement is valid even in case of the largest model depths, due to the sharp γ_{11n} array anomalies in the electrical resistivity sections.

Thesis 6

By using analogue model measurements, it was confirmed that **with ascending n value, the γ_{11n} arrays converge to the null-arrays** (which are insensitive to the 1D changes), i.e. they more and more "see through" 1D structures. The W-Sch and the W-α arrays detect 1D and near-surface 2D changes. Resistivity sections of the γ_{112} array reflect both the 1D and the investigated 2D anomalies. **The γ_{11n} (n=4-7) arrays detected only the resistivity changes due to the 2D models**.

4. Application of the results

The γ_{11n} (n=2-7) arrays are more successful than the traditional arrays in detecting bodies which have **small effect on the electric potential distribution at the surface**. They are even able to detect changes which cannot be detected by using traditional arrays.

Two types of small-effect anomaly sources: **downward finite** (prism model) and **downward infinite** (vertical plate model) models were studied. They cause small changes in the electrical potential distribution at the surface. The width of both anomaly types is small compared to the depth of the top position of the given model, and/or have low resistivity contrast with the surrounding medium. Buried wall ruins, subsurface holes (caves and mine openings) and public utilities (pipes and cables) can be assumed to have prismatic cross sections. Fractures and dyke models can be modelled with vertical plate bodies.

In **monitoring measurements**, they are supposed to detect electrical resistivity changes earlier than the traditional arrays.