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Estimation of the error made in Pole–Dipole Electrical Resistivity Tomography depending on the location of the remote electrode: Modeling and field study

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ABSTRACT

Objective: The objective was to estimate the error made in Electrical Resistivity Tomography (ERT) when Pole–Dipole array (PD) is used, as a function of the location of the remote electrode.
Methods: First, we carried out a parametrical analysis to quantify the error in the geometrical factor and in the apparent resistivity using analytical calculation and numerical model based on the general moment method. Then, the influence of the remote electrode location was studied considering PsPD (Pseudo-Pole–Dipole i.e. when the exact location of the remote electrode is used even when finite) in comparison to PDbias (Pole–Dipole bias i.e. remote electrode is considered at infinity even when finite). Anomaly Effect (AE) with new consideration of the averaged mean resistivity value was used for the illustration, results with L1 and L2-norms were compared and Forward/Reverse measurements were considered.
Results: First results showed that for the geometrical factor, a minimum Q (the remote distance divided by the half of the distance between the first and the last in-line electrodes) value of 5 at least is needed while for the apparent resistivity, a minimum of Q value between 2 and 5 would be sufficient if $\alpha = 100°$ (angle between the line BO – joining the remote electrode and the center of all in-line electrodes – and the line joining all in-line electrodes). A spread α value around 100° gave the weakest error.
Angle α around 30° was identified as giving homogeneous spread error between PsPD and PDbias data treatments. For α ~ 140°, the error made when the true coordinates of the remote electrode is not informed is higher near layer's interface if L1-norm is used. Whereas this error is more visible in deep level if L2-norm is used. Finally, experimental results showed the influence of the location of the remote electrode when “Forward” measurements are completed by “Reverse” ones.
Conclusion: Depending on in-situ conditions, the accessibility of ideal remote electrode is not always satisfactory. Our study has given an overview of the error which can be made depending on the location of the remote electrode when Pole–Dipole array is chosen. Considering valuable results obtained by other authors with this array in the literature, this drawback is counterbalanced by other advantages of this array with respect to others which do not need a remote electrode.
Practice implications: PsPD cannot be substituted with PDbias, then, it is always preferable to consider the true coordinates of the remote electrode for data treatment either for apparent resistivity or for interpreted ones, this information is also needed by Res2Dinv to compute the 3D electrical potential. Q value equal or higher than 5 is ideally to be preferred and if an angle of 100° is not possible, a value of 30° will be used for “Forward” measurement and completed with Reverse one using the same location of the remote electrode.

1. Introduction

The Electrical Resistivity Tomography (ERT) is largely used (Aristodemou and Thomas-Betts, 2000; Frohlich et al., 1996; Guerin et al., 2004a,b). One particular electrode configuration used in ERT is the Pole–Dipole (PD) array. Different names have been attributed to PD array (Szalai and Szarka, 2008), the reader is redirected to this article for details.

Because of its advantages in comparison with other arrays, one would prefer to use PD for geophysical studies. For example, it can yield better spatial resolution images than Pole–Pole, Schlumberger, γ-array, Wenner-α or Wenner-β arrays (Dahlin and Zhou, 2004). It is also more susceptible to noise contamination but may present a good compromise between resolution and signal strength: Dipole–Dipole array is more sensitive to lateral discontinuity than the PD Forward/

Abbreviations: AE, Anomaly Effect; DZ, Dahlin and Zhou; ERT, Electrical Resistivity Tomography; PD, Pole–Dipole; PsPD, Pseudo-Pole–Dipole (the exact location of the remote electrode is used even finite); PDbias, Pole–Dipole bias (remote electrode is considered at infinity even when finite).

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Reverse arrays but its signal strength is smaller than these two arrays. Candansayar (2008) showed that PD Forward and Reverse have more depth detection than Wenner, Schlumberger and Dipole–Dipole arrays for archeological purpose.

However, the principal characteristic of PD array is the use of one current electrode which is theoretically placed at infinity. It is agreed that depending on site studies and materials, this theoretical infinite location is difficult to achieve (Kim et al., 2007; Park and Van, 1991; Robain et al., 1999; Van et al., 1991). Many studies have considered the remote electrode to be at infinity, considering that interpretation of subsurface features from ERT could not lead to erroneous results with such hypothesis. Very interesting results can be highlighted in the literature with such assumption:

- Bristow (1966) modified the PD electrode array in a manner which allowed a direct graphical interpretation of the cavity targets in approximate depth, position and size.
- The PD array is ideally suited for electrical resistivity surveys along roadways (highways) in karstic region. Indeed, electrical resistivity anomalies can be interpreted as indicative of voids and lithology change (Smith, 1986).
- Yadav et al. (1997) used what they call general PD to investigate shallow groundwater. According to the principle of reciprocity, they consider either one potential or one current electrode in effective infinity which is placed perpendicularly from the current dipole or the potential dipole respectively.
- Candansayar and Basokur (2001) acquired resistivity data by application of Forward and Reverse PD arrays on an archeological site. Using this data, the authors computed four-electrode and Dipole–Dipole apparent-resistivity values without measuring these later.
- Candansayar (2008) inverted jointly Schlumberger and PD arrays data in an archeological site to find a defense wall used in the late Roman and early Ottoman Empire periods. Using electrode spacing of 2.5 m and 8 levels, after joint inversion of the data, he suggested excavation and found the buried wall.
- Longuevergne et al. (2009) used the PD array in order to constrain the geological knowledge of a hydrothermal vein in the mines at Sainte-Croix-aux-Mines, located in the Vosges Mountains, Eastern France. The ERT obtained by the authors revealed arena on top layer, covering a fractured medium. According to the authors, fractures are well defined by the array even though mixed sensitivity which we can observe was probably due to closeness of side effects.
- Cardarelli et al. (2010) proposed a joint inversion of ERT data acquired with PD array and seismic data for cavity detection. The result obtained with this array was useful to constrain seismic refraction tomography.

As a conclusion, in most of the studies we know at present, with valuable results, the impact of the remote electrode location in the ERT is not well informed. To do so is the objective of this paper, to estimate the error made:

(i) In the apparent resistivity and the geometrical factor when Pseudo-Pole–Dipole (PsPD) (use of the exact finite location of the remote electrode) is considered instead of the theoretical Pole–Dipole (PD) (when the remote electrode is really at infinity)
(ii) In the apparent and in the interpreted resistivities when PDbias (remote electrode considered at infinity even finite) is used instead of PsPD during inversion.

For that purpose, field study with different locations of the remote electrode was first made. Then, analytical and numerical evaluations of the error either in the geometrical factor or in the apparent resistivity were performed. Based on the field study, illustrations of the influence of the remote electrode location were shown (norm of inversion, type of data treatment, use of a new version of Anomaly Effect (AE)).

It should be noted that cross-hole Pole–Dipole (ERT between boreholes) which also uses remote electrode will not be considered in this paper.

2. Materials and methods

2.1. Site of study

The site of study is located in Haute Normandie region (France), in the district of Eturqueraye. Silt layer on surface with varying width (max. 11 m) underlies clay soils with silex, lying over weathered and un-weathered chalk. Chalk is not regularly weathered, thus the interface between un-weathered and weathered chalk may present depth variations.

Two Electrical Resistivity Tomography cross-sections (ERT1 and ERT2) with Forward and Reverse measurements were obtained using Syscal-Pro device (Fig. 1). The first oriented SE–NW and the second oriented NE–SW. Electrodes spacing were 5 m, with a total length of 235 m (48 electrodes). According to the conventional representation of apparent resistivity data, this length allows an investigation depth of 52.5 m on 25 levels and 850 apparent resistivity values. Different remote electrode locations were considered to perform Forward and Reverse measurements: inf11, inf12,

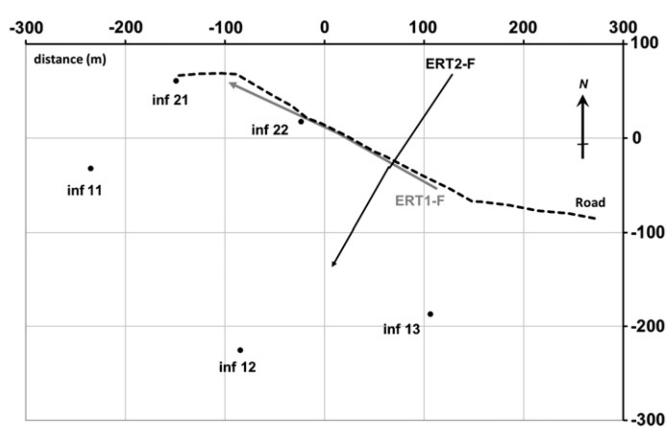

Fig. 1. Location of ERT cross-sections acquired with PD electrode array, remote electrodes locations are shown. Suffix F replaces "Forward" (ERT1-F) with the direction of measurement. Remote electrodes are numbered inf1* For ERT1 and inf2* For ERT2 (* replacing the number given to the Remote electrode).