Geophysical Research Abstracts, Vol. 7, 09948, 2005
SRef-ID: 1607-7962/gra/EGU05-A-09948

Non-linear resistivity inversion on three dimensional structures using the finite element method

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The finite element method has been used by several authors in the context of direct current electrical resistivity inverse modelling. This versatile numerical method is particularly useful for geophysical and civil engineering applications in which very varied structures can be modelled. Resistivity imaging methods are of great interest in civil or mining engineering investigations to examine tunnels structures, underground quarry columns or mine galleries (e.g. Draskovits and Simon 1992; Maillol et al. 1999; Yaramanci 2000). These applications are of prime importance for safety questions and also to plan future gallery extensions for resource exploitation purposes. Therefore, there is currently a need in developing inverse resistivity modelling codes that are better suited for imaging three-dimensional structures of more arbitrary geometries. The main features shared by these application fields are the arbitrary 3D shape of the models and the large number of parameters needed to simulate the actual geometry of the models and their inner structures. This paper presents an adaptation and new developments on the CESAR-LCPC finite element software for the inverse modelling of large 3D resistivity data sets.

An inversion code was implemented for the processing of resistivity tomographies on arbitrary 3D structures using any electrode arrangement. This algorithm uses an original strategy to avoid high-computation costs by not involving an explicit calculation of the partial derivative sensitivity matrix. A common and traditional solution to the non-linear inverse problem is formulated using a Gauss-Newton iterative approach (Loke and Barker, 1996). Nevertheless, this formulation implies the explicit calculation of the sensitivity matrix (or Jacobian matrix) which represents the changes in the model responses due to changes in model parameters. The sensitivity matrix can be sometimes analytically solved but for the electrical inverse problem on complex 3D structures a numerical solution is needed. A traditional method is to use a finite-difference approach where the sensitivities are calculated in solving the forward problem for a successively increased and decreased resistivity in every model cell which is excessively time-consuming. In general, computing an even approximated sensitivity matrix on 3D models implies unaffordable time consuming calculations. In this paper, the adjoint-state approach is used to minimize the data misfit directly (Ellis and Oldenburg, 1994; Spies and Ellis, 1995; Lesur et al., 1999; Marescot, 2004). A priori information is introduced into the optimization process by means of constraints on the model. A conjugate gradient algorithm is used to define an efficient descent direction. With this purely non-linear strategy, only two forward resolutions are needed by iteration.

Synthetic results are presented to illustrate the efficiency of the inverse modelling codes. The input data are simulated with an different commercial FE code in order to provide independent verification. These tests demonstrated that the proposed inversion algorithm was robust and does not demand strong a priori information to guarantee convergence. Synthetic modellings have shown that the algorithm can be successfully used to invert resistivity data collected on complex 3D structures using any electrode arrangement. This has important practical implications for mining and engineering applications or non-destructive investigations in which very varied structures can be studied.

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