

“Software Specifications”

Software Development of Electromagnetic Modeling for Layered Earth Model

Japan Oil, Gas and Metals National Corporation

1. Title of Software

The Software Development of Electromagnetic Modeling for Layered Earth Model. (“Software”)

2. Objective of Software

The objective of the software is to develop 1-D forward code of Controlled Source Electromagnetic (EM), which provides accurate solution and fast computing time. Conventional 1-D modeling code, for example EM1DDB, attributed to Lawrence Berkeley National Laboratory, has been widely used for calculating EM response for layered earth because of its high accuracy in numerical result, and its source code is open to the public. Further improvement, however, is required for more realistic geo-electrical models. The software to be developed in this project should satisfy the following specification and conditions described paragraph 3.

3. Scope of work

In order to achieve the objective set out in paragraph 2 above, the contractor shall perform, research, prepare and provide Geology and Geophysics Research Division in Technology Research Center of Japan Oil, Gas and Metals National Corporation (“JOGMEC-TRC-G&G”) with source code and a written report on the subjects described in paragraphs 3.(1)–3.(3) below.

(1) Improve Numerical accuracy

Conventional software has run fine for most of the cases, except when response is required at a wide Tx(source)–Rx(receiver) separation on resistive models at high ($>100\text{kHz}$) frequencies. This is exactly what land LOTEM and shallow-water marine CSEM time-domain solution requires. The Hankel transform wouldn't converge in this case. Any EM field in a layer can be generally written as an infinite integral of functional $f(\lambda\rho)$ multiplied by a Bessel function over the horizontal wavenumber (λ) (Hankel transform)

$$f(\rho, z) = \int_0^{\infty} f(\lambda, z) J_{0,1}(\lambda \rho) d\lambda$$

The functional $f(\lambda \rho)$ contains a branch cut $\sqrt{\lambda^2 - \omega^2 \mu \epsilon}$ in the denominator. Strictly speaking, the functional will blow up as $\sqrt{\lambda^2 - \omega^2 \mu \epsilon}$ resulting in unreasonable result. In most cases, however, this doesn't happen because the integral converges before $\lambda \rightarrow \omega \sqrt{\mu \epsilon}$. The convergence is usually due to the rapid decay of the functional when the earth is relatively conductive. In case when the surface layer is resistive, or results are required at distances far away from the source can happen more often than not, especially at higher frequencies.

The work, JOGMEC offers now, should look into this problem more quantitatively by monitoring the behavior of the functional as a function of the wavenumber, and a different type of numerical integral may be implemented for better convergence. A good candidate for this purpose is Gaussian quadrature, at the expense of increased computation time.

(2) Time domain solution

Conventional 1-D modeling software provides frequency domain EM responses, however, the new developed code should calculate the EM response in time-domain as well. It is obtained by FFT. It will be simply improved based on the improved result from paragraph 3(1) above. The waveforms to be considered are impulse, square and half-sine.

(3) Implement transversely isotropic conductivity

When and if the earth is anisotropic, the problem gets complicated and the differential equations for scalar potentials of 1-D structure will take different forms depending on the degree of the anisotropy. Earlier studies on this subject were limited to magnetotelluric (MT) measurements on the surface and electric dipole over a two layered earth with transversely isotropic overburden. A general treatment of anisotropy in an N-layered earth for arbitrary source and receiver configurations is not trivial. Yin and Weidelt (1999) and Yin and Maurer (2001) show some fundamental analyses on the general anisotropy in a layered earth. The proposed work should largely be based on these studies. The contractor assumes the earth is transversely isotropic in which two horizontal conductivities are equal (σ_H) and only the vertical conductivity (σ_V) is different. A careful analysis shows (*This initial result must be double-checked later once this project gets going*) that the TM and TE potentials obey

$$\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{1}{\alpha^2} \frac{\partial^2}{\partial z^2} + k_v^2 \right) A(x, y, z) = 0, \quad \alpha^2 = \frac{\sigma_H}{\sigma_V} \quad \text{for TM mode}$$

and

$$\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} + k_H^2 \right) F(x, y, z) = 0 \quad \text{for TE mode}$$

At the moment, it appears that the contractor will have to rewrite the TM mode contributions with modified boundary conditions and kernels to reconcile the scaled vertical coordinate. The other part that may require careful analysis is the coupling of the source with the proper potentials. The contractor need to calculate the source fields in an anisotropic medium, convert them to propagating potentials, and than couple them with proper TM and TE potentials.

<Reference>

- Yin, C., and Weidelt, P., 1999, Geoelectrical fields in a layered earth with arbitrary anisotropy: Geophysics, 64, 426–434.
- Yin, C., and Maurer, H. -M., 2001, Electromagnetic induction in a layered earth with arbitrary anisotropy: Geophysics, 66, 1405–1416.

4. Deliverables, Duration of Study Deliverables shall include and satisfy all of the following items:

(1) Two copies of the final report shall be completed and delivered to

JOGMEC-TRC-G&G no later than 30th September, 2010.

The report should write the followings in English or Japanese;

General description

Flow Chart

Detail theoretical Description

Operation Manual

Typical Example of Synthetic Models

(2) Two copies of electronic files (CD or DVD) of the source code with relevant files and the report shall be delivered to JOGMEC-TRC-G&G no later than 30th September, 2010. All electronic files consisting of the Report shall be prepared with Microsoft Word format, associated with necessary numeric data in Ascii format or spread sheet form, and recorded on the CD/DVDs. Such electronic files shall be editable and citable by JOGMEC-TRC-G&G.

(3) Computer Requirement

All computation by the developed software should be done on PC, assuming 2.4GHz of CUP and 2G of memory.

(4) Software Language

Fortran or C++ (not C)

5. Methodology

The contractor shall carry out all work related to the Software with such care and skill as could reasonably be expected from a professional providing the same or similar services and in conformance with industry practices and standards. The work should be done under the close cooperation with the JOGMEC-TRC-G&G researchers to exchange knowledge and improve understanding effectively through e-mail communication, workshops or seminars. (An) Interim report(s) shall be issued at appropriate time or upon requests of JOGMEC-TRC-G&G.

6. Workplace

The workplace shall either be the contractor's workplace or a place designated by JOGMEC.

End of "Software Specification"