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Procedia Earth and Planetary Science 3 (2011) 266 – 272

Procedia
Earth and Planetary Science

2011 Xi′an International Conference on Fine Geological Exploration and Groundwater & Gas Hazards Control in Coal Mines

The Application of COMSOL Multiphysics in Direct Current Method Forward Modeling

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Abstract

With point electric source as example, this paper describes direct current method forward modeling with COMSOL Multiphysics. By comparing and analyzing COMSOL Multiphysics modeling results and theoretic values of typical models, the validity and feasibility of direct current method forward modeling based on COMSOL Multiphysics is proved. Due to the powerful mesh dissection, solution function and abundant post process operation, it shows an important significance of applying COMSOL Multiphysics in geophysical modeling.

Keywords: COMSOL Multiphysics; direct current method; forward modeling; finite element method

1. Introduction

The issues of forward modeling have to be solved before using electrical prospecting to explore the structure and mineral distribution underground. The key problem of forward modeling is solving electrical field distribution rule for given geoelectric model and field source distribution, which is an important base for inverse and interpretation of electrical prospecting material. There are three methods to solve electromagnetic field distribution rule: analytic method, numerical solution method, and physical simulation method. Analytic method is well known, of which the result have typical significance, but it can be used only for electromagnetic distribution problem within a regular geometry. According to similarity theory, physical simulation method is used to inspection correctness of the result from analytic

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1878–5220 © 2011 Published by Elsevier Ltd. Selection and peer-review under responsibility of China Coal Society
doi:10.1016/j.proeps.2011.09.093

method or numerical method by means of physical model. At present, electrical prospecting usually use three kinds of numerical simulation method: finite difference method, finite element method and boundary element method[1-4]. Numerical simulation can solve electromagnetic field distribution rule under the complex conditions.

COMSOL Multiphysics software is a universal computer aid engineering software based on finite element analysis, which has a large set of functions for analyses and solution. This software includes heat transfer module, electromagnetic module, acoustics module, earth science module, chemical engineering module and structural mechanics module. It also has many pre- and post- processing functions, which provides a friendly working environment for solving both complex scientific problems and large-scale engineering problems. It lets people get rid of trivial and drab finite element programming. The other advantage of COMSOL Multiphysics is that it can solve coupled multiphysics phenomena simultaneously. Owing to these advantages, it is referred to as the first class software package for any number of coupled multiphysics fields. Not only having perfect analysis functions, COMSOL Multiphysics also provides good working environment to secondary development for its customers. COMSOL Multiphysics originates from PDE Toolbox of MATLAB. Since it officially named COMSOL Multiphysics in 2003, it has been absorbing new calculation methods and techniques, and also extending new application modules. This paper illustrates in detail the process of carrying out direct current method forward modeling based on COMSOL Multiphysics with the point electric source and line electric source as examples.

2. COMSOL Multiphysics Simulation

COMSOL Multiphysics provides two kinds of operation modes, graphical user interface style, and command style by creating scripts. Both modes provide convenience for users mostly [5]. Script mode is mainly for optimum design and second development for COMSOL Multiphysics. COMSOL Multiphysics includes three sections. Pre-process, solution, and post- process. Creating finite element model and setting load parameters are belong to pre-processing. Mesh division and solving equations are all belong to solution section. Results visualization and analysis are belong to post- processing. Fig. 2 gives the chart of geophysical forward modeling using COMSOL Multiphysics.

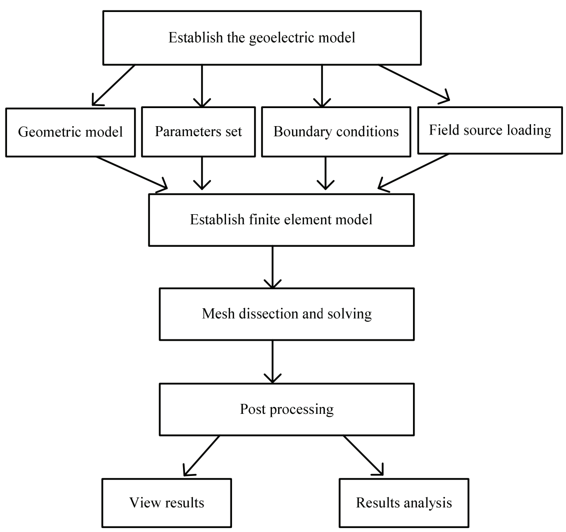

Fig.1. Chart of COMSOL Multiphysics analysis geophysical field

The base of forward modeling simulation is creating a finite element model. It must be mentioned that reasonable simplify and approximate is done when create geometric model in order to make mesh division and loading easier. For example, we can use a semi-ball substitute semi-infinite space when three dimensional simulation of point electric source is done in semi-infinite space. Simultaneously, the point electric source can be put at the sphere core of semi-ball which can make loading and mesh division easy. When dividing mesh, denser mesh is close to field source and abnormal body. More sparse mesh is far from point electric source. Thus, calculating precise and speed can be improved while total mesh number is fixed.

In fact, electrical prospecting forward modeling is solving field distribution for given geoelectric model and supply electric current. Setting boundary condition is the key to whole numerical simulation. In calculation process of COMSOL Multiphysics, the inter-boundary and ground surface boundary is automatically satisfies. For infinite far boundary, we can load according to different devices.

3. COMSOL Multiphysics Error Analysis

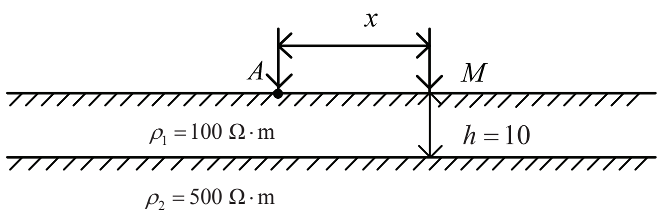

Fig.2. Sketch of two-layers geoelectric cross section

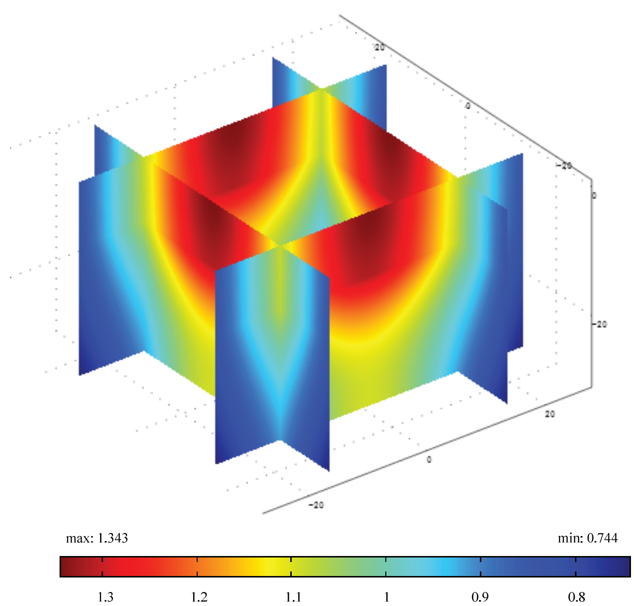

Fig.3. Electric field distribution of three-dimensions geoelectric mode

Firstly, we conducts numerical simulation of ground point electric source in the two-layers horizontal stratum with COMSOL Multiphysics，and compare the simulation value and the analytical value of potential. Fig. 2 shows the sketch of two-layer geoelectric cross section. The first layer has resistivity ρ_1=50$\Omega\cdot$m , depth h_1=5m , and the second layer has resistivity ρ_2=500$\Omega\cdot$m . With unipolar power supply, electric current intensity is 1A; current electrode is set at the 0 position on the surface, observation distance is 50m. As to ground point electric source in the two-layer horizontal stratum，the ground potential distribution analytical expression is as follows [6]

$$u=\frac{I\rho_1}{2\pi}\left\{\frac{1}{x}+2\sum_{n=1}^{\infty}\frac{\left(\frac{\rho_2-\rho_1}{\rho_1+\rho_2}\right)^n}{\left[x^2+(2nh)^2\right]^{1/2}}\right\}. \tag{1}$$

By applying COMSOL Multiphysics to the geoelectric model expressed in Fig. 2 to conduct three dimensional forward modeling numerical simulation，we can obtain the following potential distribution personated in Fig.3. Table 1 show when point source A locates at 0 position，the comparison between simulation value and analytical value of the potential，while point M moves from 0.5m to 25m. As it is shown in Table 1, in the vicinity of point electric source (less than 2 m)，the closer to point source， the bigger potential error is；the farther the distance to point source is， the smaller the error is；and the error tends to 0 when it is close to the borderline. When it is 0.5m to 3m to the point source, the maximum relative error is within 5.14%. For the range of 15m to 25m, the maximum relative error is less than 3.23%. Obviously, these results are sufficient to illustrate that the current method，applying COMSOL Multiphysics to conduct electrical prospecting three-dimensional forward modeling numerical simulation，can obtain reliable calculation results and satisfactory accuracy.

Table 1. Comparing of potential analytical values and simulation values of three-dimensions geoelectrical model

x(m)	analytical value(v)	simulation value(v)	error (v)	relative error
0.5	16.832713	15.967131	0.865582	5.14%
2	4.892753	4.948983	0.056230	1.15%
3	3.562076	3.616448	0.054327	1.53%
5	2.487495	2.545269	0.057774	2.30%
8	1.860420	1.915346	0.054926	2.95%
10	1.636528	1.688789	0.052261	3.19%
15	1.300783	1.342781	0.041999	3.23%
20	1.096511	1.126108	0.029597	2.69%
25	0.950910	0.965581	0.014671	1.54%

4. Forward Modeling Simulation Example

Model: there is a cylindrical conductive object under the horizontal evenly ground (resistivity ρ_1=100$\Omega\cdot m$), and its length is much greater than the cross-sectional radius. There is a rectangular high resistance object ten meters away from the location of the cylindrical conductive object, whose length is much greater than its height and width, and its trend is in line with the cylindrical conductive object. Both of the two objects are set at the depth of 4m. Cross-sectional radius of cylinder $r=2$ m, resistivity ρ_2=10$\Omega\cdot m$. Rectangular cross section is $6\text{m}\times4\text{m}$, the resistivity $\rho_3=500\Omega\cdot\text{m}$. Geometric model can be shown in Fig. 4.

Loading a point of dipole current source, powered-up at point *A* and point *B*, the current strength at point *A* is 1A, the current strength at point *B* is -1A. Fig. 5 shows the electric field distribution of the model when power supply point *A* locates at -10m (reference 0 point locates at 150m, thus point *A* locates at 140m position), while power supply point *B* locates at 10m (reference 0 point locates at 150m, thus point *B* locates at 160m position). From Fig. 5, we can see repellent effect to electric current of the rectangular high resistance object anomaly, while attraction effect to electric current of the cylindrical low resistance object anomaly.

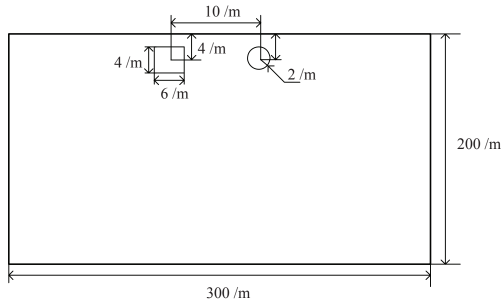

Fig.4. The geometric model sketch

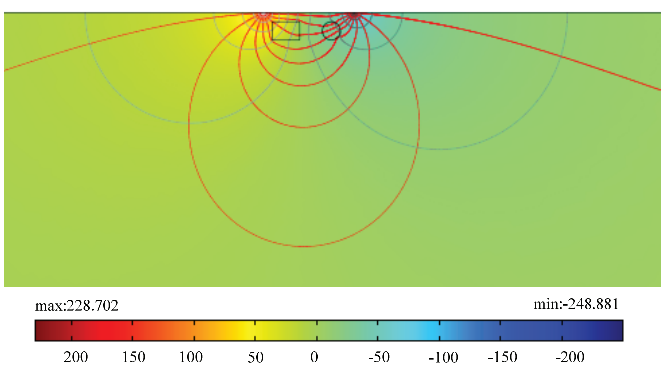

Fig.5. Electric field distribution of the model with fixed power supply electrode position

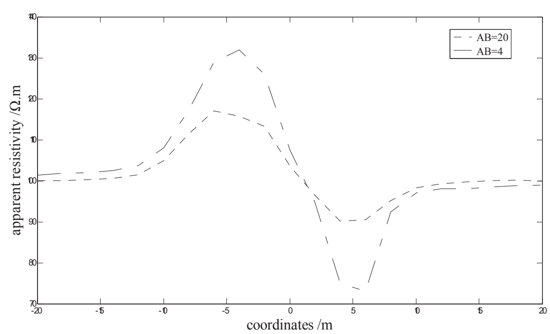

Fig.6. Apparent resistivity curves with different power supply electrode position

Fig. 6 shows the apparent resistivity curve comparison chart when polar dipole current sources AB are 4m, and 20m respectively, measuring electrode distance MN of 1m. It's can be seen from Fig. 6 that at the position of -4m, apparent resistivity value is 115.7 $\Omega \cdot m$ when polar distance AB equals 4m, while the apparent resistivity value is 131.9 $\Omega \cdot m$ when polar distance is 20m. Compared to the background resistivity $100\ \Omega \cdot m$, the latter has a higher abnormal apparent resistance. At the position of 4m, apparent resistivity value is 90.2 $\Omega \cdot m$ when polar distance AB is 4m, while the apparent resistivity value is 75.1 $\Omega \cdot m$ when polar distance is 20m, compared to the background resistivity $100\ \Omega \cdot m$, the latter has a lower abnormal apparent resistance. This indicates that when the anomalous object is entirely located within the exploration depth, the c abnormal is very evident, while if the anomalous body is not fully in the exploration depth range, there is an abnormal in the anomalous and the trend is consistent with the former, but not so evident as the former.

Fig.7shows apparent resistivity cross section of symmetrical quadrupole device when $MN = 1$, $AB = 4n \quad (n = 1,2,3,4,5)$. Fig. 7 indicates that between -8m to -2m a high resistance abnormal body exists, and the top of it appears to be a straight line, which happens to reflect the width and shape of a rectangular anomaly in forward modeling. Between 3m to 7m there also exists an anomal low resistance whose scope is in accordance with that of the given cylindrical low-resistivity anomaly in model. The top of the anomaly is approximately an arc curve, which could also match the cylindrical anomaly in model. In addition, the tops of two anomalies are located in the position of $n = 3$ (corresponding to the actual depth of 2m), which is consistent with the model set. It is noteworthy that, Fig. 7 shows that at point 0 (corresponding to 150m position) with the increase of n the resistivity rises from $104\ \Omega \cdot m$ up to $113\ \Omega \cdot m$, and then reduces to $106\ \Omega \cdot m$, compared to the background resistivity $100\ \Omega \cdot m$, this is a relatively high resistance region. Obviously, this could be due to rectangular high resistance anomaly area is greater than circular low resistivity anomaly area. Consequently, such high resistance has greater influence to this point, although the distances from centers of the two anomalies to point 0 are the same.

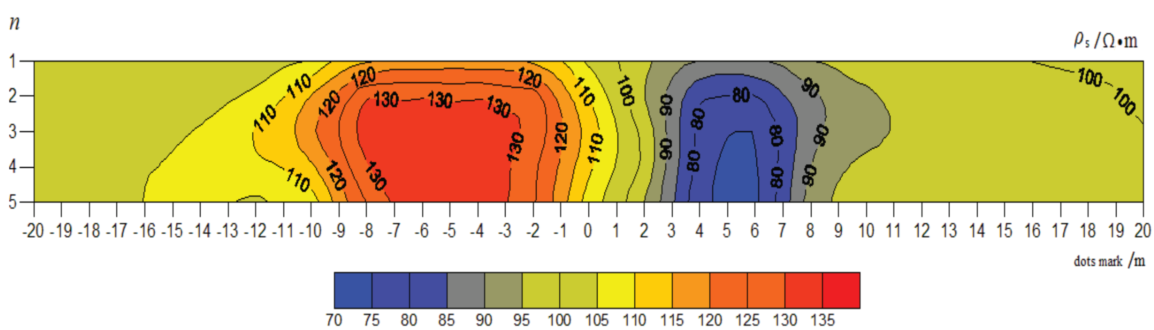

Fig.7 . Apparent resistivity cross section of symmetrical quadrupole device $AB = 4n \ (n = 1,2,3,4,5)$, $MN = 1$

5. Conclusion

Numerical simulation results obtained from COMSOL Multiphysics proves the reliability and feasibility to investigate the direct current method forward modeling. Its powerful numerical computing and visualization post-processing features make forward calculation simple and informative. Using COMSOL Multiphysics script can flexibly achieves a variety of direct current method forward modeling, which makes COMSOL Multiphysics a powerful tool for secondary development. Numerous advantages of COMSOL Multiphysics forebode that it has a broad application prospects in geophysical research.

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