Research of ANSYS Simulation Studied on AC BEAM Method in Geological Exploration

Li YAO and Yang WANG
Shenyang University of Technology, Shenyang city, Liaoning Province, China

Keywords: ANSYS simulation, BEAM, Induced polarization method, Double-Pole device.

Abstract. AC BEAM induced polarization method plays a very important role in advanced geological exploration. This study established simulation model based on BEAM double-pole detection device in the ANSYS electric simulation module environment. Simulation process includes pre-processing, solution, after processing and then summarizes the relationship between obstacle resistivity and measuring voltage of simulation. Changing location, offset angle, size of the obstacle and the emission electrode, study on the impact of measurement results. Build the experimental platform and compare the experimental results with the simulation results, the change trend of experimental and simulation results is same. The research results have present practical guidance for the BEAM application.

Introduction

‘There is a need to tunnel, must be prospected before’ is the principle of all underground prospection engineering. Along with the increasing number of the tunneling engineering, tunneling technology is becoming more and more mechanization and automation. So the advanced prospection level is difficult to meet the requirements of fast and efficient tunneling engineering. And then the contradiction between "tunneling and prospecting" restricts the development of tunneling engineering.

In recent years, scholars have made a deep research on the geological structure and strata water-bearing property of advance geological exploration working face, and achieved remarkable results. Usually the method of prospection is mainly including: seismic reflection wave, DC focusing method, magnetic resonance, transient electromagnetic, etc.. But these methods in achieving the advanced exploration of tunnel still have a series of problems, such as the separating exploration, inefficient detection [1]. BEAM method is based on the induced polarization method working by the different physical and chemical properties of rock causing different geoelectric field. BEAM can be installed on the TBM machine, in order to prospect the geological conditions in front rapidly. Not only to make the detection more accurate, but also save the human resources, so the BEAM method has a good effect for tunneling geological structure and water-holding condition.

ANSYS is general finite element analysis software, which integrates the structure, fluid, electromagnetism and heat in one [2]. It has the merits of greater generality, higher accuracy and the obvious advantages in the process of solving 3D electrical field problems.

Operational Principle

BEAM

The working principle of BEAM device is based on the induced polarization method. The complex electrochemical reaction of underground rock called polarized electric field occurs under the action of artificial electric field, which increases with the increase of time, and forms a total electric field with artificial electric field. After a period of time, the total electric field tends to saturation, disconnect power, the polarized electric field disappears, and then the polarized electric field continues to discharge until decaying to zero. By measuring and calculating the size of the polarized electric field, the resistivity and moisture content of rock will be knew [3].
BEAM system has three electrodes: exciting electrode $A_0$, guard electrode $A_1$ and earth electrode $B$. In order to obtain the obvious effect of the induced polarization, the frequency ($f_1$ and $f_2$) of the excitation voltage must be two large differences in low frequency. The rock can be induced fully under low frequency voltage. The excitation voltage in frequency $f_1$ is recorded as $\Delta U_1$, and the other excitation voltage is recorded as $\Delta U_2$ [4]. Percentage Frequency Effect (PFE) and Resistivity ($R$) are two important parameters of induced polarization method, and the geological structure can be obtained by these parameters.

\[
R_{f1} = \frac{U_1}{I_1}, \quad R_{f2} = \frac{U_2}{I_2}
\]

\[
PFE = \left( \frac{R_{f1} - R_{f2}}{R_{f1}} \right) \times 100% \tag{2}
\]

\[
PFE = \frac{\Delta U_1 - \Delta U_2}{\Delta U_1} \times 100% \tag{3}
\]

PFE is a characteristic parameter that measures the ability of storing electrical energy and reflects the degree of geological polarization. Rock property and porosity have direct influence on the polarization effect. When the rock mass is compact, with metal or water, the porosity is low and easy to be polarized, the value of PFE is higher than no obstacle. So the structure and properties of the geology can be judged according to the value of PFE.

**Detecting Device**

The devices used in the induced polarization method are: central gradient device, dipole device, near field source device and composite profiling device. According to the tunneling requirement, every electrode can be closely installed on the near field source device, which is convenient to control each electrode in the TBM [5]. In the BEAM tunneling process, obstacles in front of the tunneling, double-pole device included in near field source devices is used for tunneling progress. Double-pole device is shown in Figure 1.

![Figure 1. Detection device of double-pole.](image)

The detection process of double-pole device is that moving exciting electrode (A) and detecting electrode (M), changing the distance between AM, calculating the PFE of every structural layer aim to determine the location of obstacles [6]. Exciting electrode (B) and detecting electrode (N) are located in the "infinity" behind tunnel face (Infinity is a relative concept). In the actual detection process, B (N) is a iron very far behind the TBM machine.

**ANSYS Simulation Study**

Voltage distribution and electric-field distribution can be obtained in the atmosphere of ANSYS electric field module. The relationship between the voltage and the resistivity is obtained by analyzing the curve of the simulation voltage with the resistivity and shift position, preparing for experiments.
Modeling

According to the ANSYS finite element modeling principle, the BEAM system is modeled and solved in 3-D simulation. Before modeling, we must set the parameters of various materials, electrode material is iron, the area behind tunnel face is air, and detection area is ground. The resistivity of the air, the ground and the iron electrode are: 1e6 $\Omega\cdot$m, 100 $\Omega\cdot$m, 1.75e-8 $\Omega\cdot$m, and the dielectric constant of the three are: 1, 10, 1e3.

The BEAM system has nine exciting electrodes, which distributed on the circumference of a radius of 0.5m. Each time one electrode supplies power; the others are used as the measuring electrodes. There are nine guard electrodes distributing on the circumference of a radius of 1m, whose voltages are the same as the exciting electrodes. The whole size of model is $5 \times 8$ m cuboids; material in front of the tunnel face is ground, due to TBM’s continuity of operation, and behind of the tunnel face is air. Schematic diagram of the BEAM advanced detection is shown in figure 2.

![Schematic diagram of BEAM advance detection.](image)

It should be noted that the electric field distribution generated by the point source is not obvious, so exciting electrodes and guard electrodes are small sphere models instead of points. In addition, at the boundary of the air area and the ground area, there is a difference in resistivity and dielectric constant shielding electric field transfer, so the electrodes should be built in the ground area rather than the air.

Simulation Results Analysis

ANSYS has two post processors: general post processor POST1 and time history post processor POST26. POST1 shows the simulation results on point in time or frequency. POST26 shows space simulation results with time. Simulation analysis of electric field includes static analysis and harmonic analysis, this paper uses the method of static analysis.

If there is no guard electrode, the electric field line will directly point to the ground electrode at infinity, the distance that can be detected will be short. But with the protection of guard electrode, the electric field line will be forced to push forward by the electrode voltage, increasing detection range. The electric field line distribution in the 2-D simulation is shown in figure 3.

From the simulation we can see that the middle point is exciting electrode A0, on both sides locate guard electrodes A1, and the rear point is ground electrode. When only the exciting electrode A0 be supplied power, and then meshed by free meshing, the electric field intensity $E_1$ of node(-4.22477, 0.0746182, 0) is 1.10859e12 v/m. On the basis of the above, the same power is supplied to two guard electrodes A1, the electric field intensity $E_2$ of same node is 3.23726*e12 v/m. $E_2 \approx 2.92E1$, so the guard electrodes can make the detection distance deeper.
Modeling in 3-D simulation, exciting electrodes and guard electrodes all are supplied 60v voltage. There is a rectangular obstacle in two meters from the front of the exciting electrode. The electric field distribution displayed in POST1 is shown in figure 4.

With reference to Fig. 4 we can see that the electric field intensity is getting smaller and smaller with the depth of detection, and there is almost no electric field in the air area. When an obstacle is encountered, because of induced polarization, the electric field on the interface changes obviously. The outstanding performance of its transmission characteristics. Contour electric field distribution displays the electric field transfer characteristic intuitively.

**The Influence of Parameters on Simulation**

Electric field and voltage distribution Contours can be displayed in POST1 and the curve of simulation voltage with the position will be proposed through Path operation command. When the distance between obstacle and exciting electrode exceeds 5m, the simulation voltage is essentially constant, so the best detection distance is within 5m. Keep the excitation voltage and the size of obstacle constant. Changing the resistivity and position of the obstacle along the direction of the Z axis, ANSYS measures the simulation voltage in each case. The detection process is considered as a closed circuit, and then calculates the voltage value according to Ohm's law. Taking the closest point of measurement as an example, the measured voltages in three kinds of obstacles located at 1m, 2m, 3m, 4m are obtained respectively. The results of the measurement are shown in Table 1. (Measured voltage /V)

<table>
<thead>
<tr>
<th>Obstacle</th>
<th>1/m</th>
<th>2/m</th>
<th>3/m</th>
<th>4/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>28.43</td>
<td>30.36</td>
<td>30.49</td>
<td>27.36</td>
</tr>
<tr>
<td>Rock</td>
<td>24.3</td>
<td>28.56</td>
<td>28.32</td>
<td>25.36</td>
</tr>
<tr>
<td>Air</td>
<td>21.25</td>
<td>25.35</td>
<td>25.13</td>
<td>20.36</td>
</tr>
</tbody>
</table>
With reference to Table 1 we can know that in case of the same obstacle, the voltage varies significantly between 2-3m, therefore, the induced polarization is sufficient in that location. In other words, the best position for the obstacle is at 4-6 times of the radius of the excitation sphere. If the position of obstacle remains constant, the more the resistivity, the less the voltage. When Z coordinates of obstacle remains constant, changing X, Y coordinates, simulate the voltage distribution under different offset positions. The measurement results are shown in Figure 5.

![Figure 5. The curve of the measurement results with the shift position.](image)

Figure 5 shows that voltage curves are presented at the central point of the obstacle along X axis 0m, 1m, 2m, the excitation effect is the most obvious when no offset, at 2m the transmission curve is the same as no obstacle. So the larger the offset is the more obviously the induced polarization effect.

In addition to the position and offset of the obstacles, the size also influenced induced polarization effect. When the offset is zero, the obstacle in front of 2m volume changed from 1m³, 4m³, 16m³ three states, the voltage transfer of 16m³ barrier is the biggest, the results shows that the larger the obstacle is, the more obvious the excitation polarization is.

**Experimental Verification**

According to the two-polar detection principle, set up a real exploration and measurement model in the laboratory. Using andirons and concrete base built a rectangular space, which is filled in a volume of 1x1x3 m sand. On the test cross section of 1x1m, according to the location specified in the simulation, arrange 9 inner exciting electrodes within radius of 0.25m and 9 outer guard electrodes radius of 0.5m. A square-wave voltage source which is homemade, voltage in the 60v, 100v, 150v can be adjusted, and frequency can be adjusted. Because of the restricted conditions, electrode distance and obstacle distribution distance are half size at the same time, but it does not effects the measurement result. Obstacle signal can be received by acquisition card and transferred to PC to observe.

With the change of the distance, the experimental results and trends of the simulation results are basically the same. Due to the external environment, the irregular shape of the obstacle and other factors, the experimental data is small than the simulation data. Take low obstacle experiment data as an example, each voltage of the measurement point is the average value of all measurement point. The result compared with simulation data shown in Figure 6.
When the obstacle in front of the emission point between 1~1.5m, the distance is 4~6 times than electrode radius. And the simulation results are consistent, consequently, the induced polarization distance best detection is 4~6 times of electrode radius. When the obstacle vertical and horizontal offset, the measurement result is basically same the data without obstacle, induced polarization is not obvious and it is not conducive to the probe.

Summary

Through theoretical research and experimental analysis, we get the following conclusions:
(1) Using BEAM method geological exploration technology to detect obstacles, the results matched with forward simulation results, show the feasibility of the method.
(2) Analysis of electric field model is built by ANSYS finite element simulation software. By changing obstacle's position and electrical resistivity, the simulation shows transfer process of the voltage and electric field.
(3) When obstacle longitudinal movement is in the 4~6 times to the excitation electrode radius, the induced polarization have the most obvious effect; When obstacle lateral movement, the smaller the offset is more obvious, the large the size if the obstacle excite is more obvious. Therefore, the optimum conditions for detection are large enough obstacle, in front of the excitation electrodes and 4~6 times of the excitation electrode within the radius of the electrode.

Reference


