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Application of AGI and EH4 in geological exploration of open pit slope

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Abstract. Both AGI high-density electrical method and EH4 magnetotelluric method are currently used in the field of engineering geophysical exploration with relatively satisfactory results. By combining AGI and EH4 detection methods and co-applying them in the geological exploration of the open pit slope of metal mine, the advantages of high-density electrical method such as strong anti-interference ability, high precision of shallow survey, large depth of EH4 detection and wide coverage can be effectively combined. In this way, the abnormal geological structure of the mine slope site is detected more accurately, and it is concluded that there are two groups of large fault structures in the western slope of this mining area. And the structural belt is wide, the water-rich area is large and the depth is deep, which has adverse effects on the overall stability of the mine slope, and also provides guarantee for the follow-up mining design and safety production.

1. Introduction

Engineering geophysical exploration is an exploration method of solving geological problems, which is based on the difference of physical properties of underground geological bodies, through the observation of the changes of natural or artificial tectonic physical fields by instruments, to determine the underground distribution and morphology of geological bodies. Common methods mainly include electrical method, magnetic method, seismic method, elastic wave test, tomographic imaging, etc. Among them, the high-density electrical method and the magnetotelluric method are all electro-explorations, but their working principles and applicability are different [1,2]. The high-density electrical method, which began in the 1970s and 1980s, is an array exploration method using artificial electric field sources. As one of the most widely used methods in the field of engineering geophysics, it has the advantages of rapid and efficient surveying, abundant information and high accuracy. Its exploration effect has been widely recognized in the field of engineering at home and abroad. Although EH4 magnetotelluric method is also a kind of electrical prospecting, it makes use of the principle of magnetotelluric method to combine the artificial electromagnetic field and natural electromagnetic field effectively, which makes up for the instability of natural electromagnetic field and the weakness of interference and signal, and it not only has the stability of active electrical prospecting method, but also has the energy saving and portability of passive electromagnetic method. Due to its advantages of large depth and high precision, it has achieved good application results in mine exploration and metallogenic

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exploration in mountainous areas [3~6].

In this paper, AGI and EH4 are combined to be used in the geological exploration of open pit slope of metal mine, which has effectively combined the high anti-interference ability and high precision of shallow survey of AGI, and large detection depth and wide coverage range of EH4. It can more accurately detect concealed geological conditions on the mine slope site and provide reliable guarantee for efficient mining and safety [7~12].

2. AGI high-density electrical method and EH4 magnetotelluric detection method

2.1Working principle

（1）AGI high-density resistivity method

As a variant of the conventional resistivity method, the AGI high-density resistivity imaging system uses the high-density resistivity method, which is still based on the electrical difference between rocks (ores), to solve various engineering geological problems by observing and studying the underground distribution rules and characteristics of artificial electric field. By placing grounding electrode artificially, applying dc current to underground to form an electric field, and using the corresponding instrument on the surface to observe the variation of electric field distribution, it studies the distribution of conduction current in strata under the action of artificial electric field to infer and analyze the types and states of the geological bodies. It finally achieves the goal of solving geological problems [13~14].

The different resistivity of the geological body composed of rock (ore) stones is the basic condition for the high-density resistivity method to explore, infer and explain the underground geological body. The measurement circuit diagram is shown in figure 1, where A and B are power supply electrodes, and M and N are measurement electrodes. According to the electric field theory, the formula for calculating the resistivity between M and N under the stable current field is as follows (1):

$$\rho = \frac{2\pi}{\left(\frac{1}{AM} - \frac{1}{AN} - \frac{1}{BM} + \frac{1}{BN}\right)} \times \frac{\Delta U}{I} = K\frac{\Delta U}{I}(\Omega \bullet m) \tag{1}$$

For the non-uniform electric field, the resistivity value obtained is the comprehensive response of the underground half space body, which can be referred to as the apparent resistivity due to the influence of topographic height, uneven underground medium, overlapping rock (ore) rocks and crisscross fault fractures, etc., and its calculation formula is as follows:

$$\rho_S = \frac{K \cdot MN}{I} j_o \cdot \rho \tag{2}$$

In equations (1) and (2) above, K is the electrode alignment coefficient, which is related to the measurement device mode; Δ U is potential difference; I is the current; J0 is the current density between M and N; ρ is the resistivity of homogeneous isotropic rocks. Finally, according to the resistivity data collected from the underground rock (soil) layer, the distribution of stratigraphic geological bodies in the survey area is analyzed by using the Zhody inversion method or the least square method.

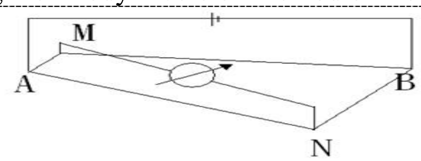

Figure 1. Schematic diagram of measuring electrode.

(2) EH4 magnetotelluric detection method

The main principle of EH4 magnetotelluric detection method is to use the natural magnetic field signals in the universe, such as solar wind, lightning and so on, which are incident to the earth as the source of the excitation field, also known as the primary field. This field source is plane electromagnetic wave, which is vertically incident to the earth medium. According to the theory of electromagnetic field, induced electromagnetic field will be generated in the earth medium, which is the same frequency as the primary field. Generally speaking, higher frequency data reflect the electrical characteristics of the shallow part, while lower frequency data reflect the deeper electrical characteristics. When the earth resistivity structure is constant, the continuous vertical sounding can be obtained by changing the signal frequency. Therefore, by observing the information of electric and magnetic fields in a broadband band and calculating the apparent resistivity and phase, the geoelectric characteristics, underground structure characteristics and distribution of the earth can be determined [15~16].

The propagation of electromagnetic wave in rock (soil) layer follows Maxwell equation. If it is assumed that most underground rock and soil are non-magnetic materials, and are uniformly conductive in macroscopic and without charge accumulation, the apparent resistivity of the earth can be obtained as shown in equation (3). For horizontal stratified land, as the penetration depth (skin depth) of the earth is related to frequency, the resistivity calculated according to (3) will change with frequency. At this point, it is called the apparent resistivity, and skin depth is shown in equation (4). If E and H are measured in a broadband band and the apparent resistivity and phase are calculated from this, the underground structure can be determined to achieve the purpose of solving geological problems.

$$\rho = \frac{1}{5f}\left|\frac{E}{H}\right|^2 \tag{3}$$

$$\delta = \left(\frac{2}{\omega\mu\sigma}\right)^{1/2} \approx 500\left(\frac{\rho}{f}\right)^{1/2} \tag{4}$$

2.2Working methods and processes

The high-density electrical method can be used for multiple array combined measurements, with multiple device forms. The overall arrangement is shown in figure 3. This paper mainly introduces the mode of wenner device. Wenner device is highly sensitive to the underground vertical resistivity change of the middle part of the whole arrangement, which is more suitable for detecting the structure of vertical change (such as horizontal layer structure), and slightly less capable of detecting the structure of horizontal change (such as narrow vertical structure). The wenner device has the strongest signal strength and is a good choice in the case of strong geoelectric interference. However, the data arrangement pattern of the wenner device is trapezoid. In two-dimensional exploration, the deeper the depth is, the smaller the horizontal coverage is. Therefore, if the polar distance is too large, the effective width of the detection is narrower. The detection depth is about 3 ~ 4 times of the abnormal body size of the object, as shown in figure 2.

The field diagram of EH4 magnetotelluric detection is shown in figure 4. Four measuring electrodes in the vertical direction of X and Y should be arranged on the site, and two magnetic bars that are perpendicular to each other should be arranged at the same time, which can be expressed as Hx and Hy. The grounding electrode and transmitting antenna should also be arranged, and the host should be connected. Then, according to geological conditions and site conditions, select appropriate sampling parameters for data collection, and confirm the validity of the data on site.

The measurement process of AGI high-density resistivity method and EH4 magnetotelluric detection are basically the same, and can be divided into three independent steps: (1) design the measurement method according to the range of measurement; (2) site wiring Settings and measurement; (3) process data and perform inversion calculations.

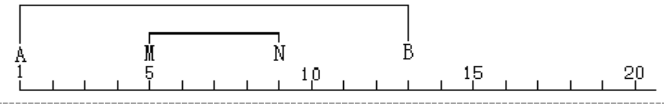

Figure 2. Schematic diagram of wenner device

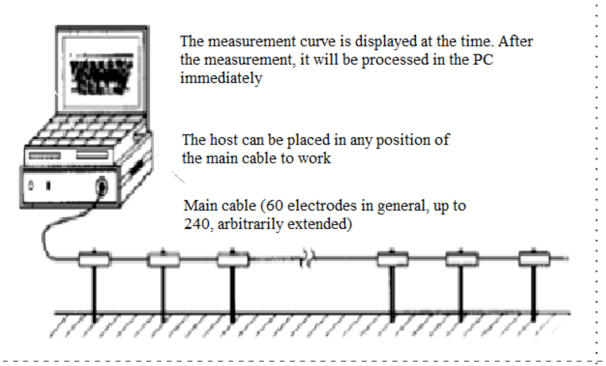

Figure 3. Schematic diagram of AGI distributed high-density electrical detection field layout.

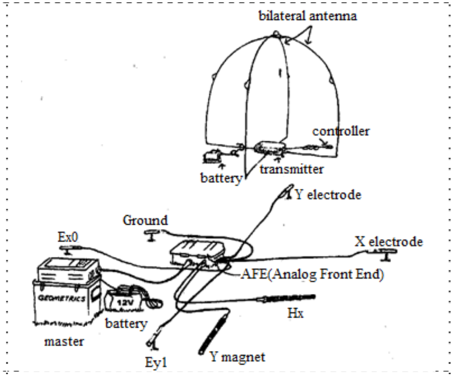

Figure 4. Schematic diagram of EH4 detection work arrangement.

3. An application example of geological exploration of open pit slope

3.1The survey of detection area

An open-pit metal mine is located in the southern section of CuiHong mountain of the Xiao Hinggan Mountains – ZhangGuangCai Mountain polymetallic metallogenic belt. In the region, the geological structure is complex, and the magmatic activity is strong, and the strata show little. The inner strata of the mining area are dominated by granitic rocks of different ages, and the strata are distributed sporadically in the rocks, located in the south of YiChun-YanShou geosyncline folding system. The exploration work area is the western and northern slope of the mine, which is located in the low mountains and hills area of Xiao Xingan Mountains. The topography is high in the north and low in the south, with large topographic fluctuations and a relative elevation difference of 274.5 meters. The surface vegetation in the area is developed and the forest is luxuriant. Shrubs and secondary forests grow where there are no swamps in the gullies. This area has poor visibility conditions and difficult operation and there are a few loose quaternary holocene deposits in the outcrop layer, mainly distributed along gullies and valleys, most of which are intrusive rock masses.

3.2Field exploration and results analysis

3.2.1Detection profile layout

According to the specific geological and topographic conditions of the exploration area, a total of 6 exploratory profile lines are arranged on the site, and the survey lines are arranged along the inside of the mining pit to the outside, and each survey line is perpendicular to the open-pit boundary line. Among them, EH4 realizes the full coverage of 6 test lines, and AGI selects 1#, 3# and 6# for coordinated detection. The field layout of the test line is shown in figure 5. The polar distance of AGI high-density resistivity method is 6 meters, and the length of a single profile line is 360 meters, and the designed detection depth is within 50-100 meters. EH4 magnetotelluric detection is provided with 98 points, whose polar distance is 30 meters. And the designed detection depth of EH4 magnetotelluric detection is within 100-1000 meters, which is effectively connected with the AGI detection depth.

3.2.2AGI inversion and analysis of detection results

The data were collected by dipole - dipole and wenner. Due to the influence of field geological and environmental conditions, the data measured by the dipole-dipole method is very poor. So the analysis results are mainly based on the wenner method. Taking the 1# line as an example, the measurement takes the inner side of the mining pit as the starting point and the outer side as the end point, and the inversion section of the data obtained by the wenner collection method is shown in figure 6.

Figure 5. Layout of survey line in the detection area.

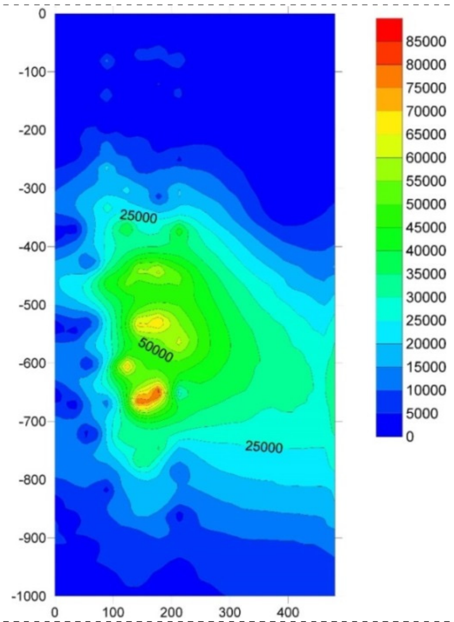

Figure 7. Two-dimensional inverse cross -section diagram of probe line 1.

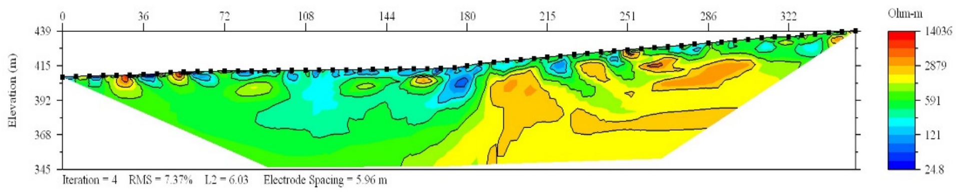

Figure.6 Two-dimensional inverse cross-section diagram of 1# line using wenner method.

It can be seen from figure 6 that there is a significant difference in resistivity between the left and right sides. The resistivity on the left side distributes within 20-1000 Ω/m, and the resistivity on the right side distributes within 1000-14000 Ω/m. The depth of detection is about 94 meters. Based on the existing geological data and inversion map, it can be inferred that the difference of resistivity on the left and right sides is caused by the structure in the stratum, which is located in the middle of the exploration profile, and the corresponding position can be inferred that the structure is near the boundary line of the pit, showing a north-south strike and a steep dip. According to the existing geological data, the structure is consistent with the F3 fault. In contrast with the location of the pit boundary line and exploration profile, the fault and boundary line almost coincide. Therefore, the fault has great influence on the slope when the slope is excavated. Where the profile line is located, the left profile line is in the gully, and the right profile is in the mining area. The right profile is high and the left profile is low. The gully strata are mainly quaternary alluvial-diluvial strata, and the underlying strata are broken granite formations. The water-bearing rock in the gully is the alluvial deposits of fluvial facies, eluvium and deluvium of eluvial facies and slope wash facies, of which replenishment source is vertical replenishment of atmospheric precipitation and lateral replenishment of weathering fissure diving, discharged in LuMing creek by underground runoff. Combined with exploration profile inversion map and surface topography map, it can be seen that the resistivity of the left stratum is lower than that of the right, and the left stratum is located in the gully. The stratum is rich in water and has a depth of more than 80 meters, so it is particularly important for the stability of the slope. The influence of water on the slope should be fully considered in the process of slope excavation.

3.2.3EH4 data processing and profile analysis

EH4 data processing adopts the unique Born approximation inversion developed by Lawley Company, and combines conjugate gradient least square method (CGLS) and rapid relaxation inversion (RRI), and optimizes the gauss-newton method by the smoothing constraint to approach the ideal interpretation imaging through multiple iterations. Taking 1# line as an example, the measurement takes the inner side of the mining pit as the starting point and the outer side as the end point. The cross-sectional results after inversion are shown in figure 7.

The location of its probe profile coincides with that of the AGI high-density electrical profile, and the detection inversion depth was about 1000 meters. It can be seen from figure 7 that the resistivity distribution within the detection profile is significantly different. For -300 meters to -700 meters in depth range, there is a significantly high resistance area, and most of its resistance value is about 25000 ~ 50000 Ω/m range, part of which is about 70000 ~ 80000 Ω/m range. It extends from north to north west direction. Based on geological data and inversion map, it can be inferred that this difference area should be caused by the existence of tectonics in the stratum, and the inversion shows that the tectonics tend to strike north to north and west, and the dip Angle is relatively steep. According to the existing geological data and surface topography map, the structure is consistent with the F3 fault and it is consistent with the aforementioned AGI inversion results. This indicates that the fault tectonic belt tends to the southeast, the lower part is relatively wide, and the broken rock layer is mixed in the middle, so part of it presents an obviously high resistance value region. In addition, according to the topographic map of the surface, the structure is located on the outside of the slope.

At the same time, a comprehensive analysis has been carried out on the six profile inversion graphics of EH4 magnetotelluric detection, and the three-dimensional slicing technology has been used. The results are shown in figure 8 as a whole.

(1) The high-resistivity abnormal body in the figure presents certain continuity, indicating that the structure inferred has continuity and integrity.

(2) There are two groups of structures in the strata of the detection area, of which one group is presumed to be F3 fault and the other group is F1 fault.

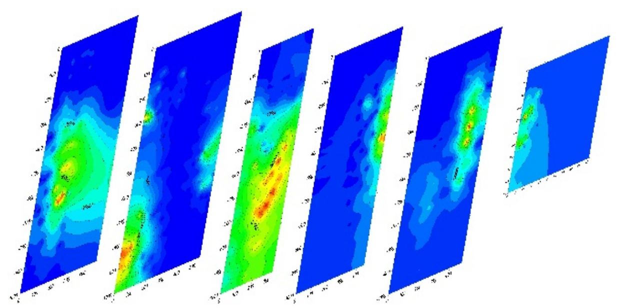

Figure. 8 three-dimensional slice map.

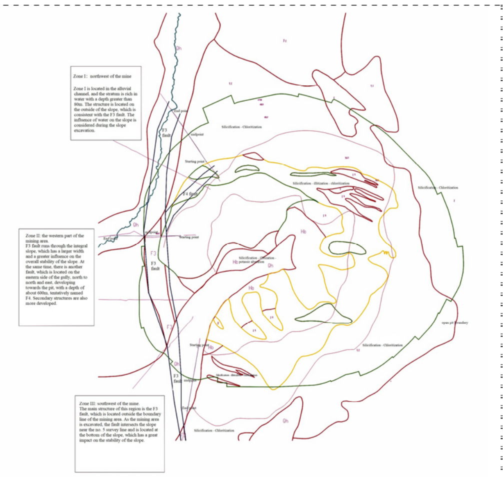

Figure. 9 geophysical results analysis.

(3) The F3 fault runs through the western part of the pit, showing a north-south direction and cutting off the western side slope. The fault has great influence on the overall stability of the slope. In the northwest and southwest, the fault is located on the outside of the pit. The slope is prone to landslide. In the central part of the west side of the pit, the fault lies in the inner side of the pit, but as the slope is excavated, the fault will intersect with the bottom of the slope, which is not conducive to the stability of the slope.

(4) The development of F1 fault starts from the central part of the west side of the pit and is located on the eastern side of the gully, showing a trend of north to north and east, and develops towards the inner part of the pit with a depth of about 600 meters.

4. Conclusion

AGI high-density electrical method and EH4 magnetotelluric detection method have their own advantages and application range, and their effect on the exploration of the abnormal geological structure of the open pit slope of metal mine is relatively ideal. According to the above practical engineering application, it can effectively combine the shallow and deep exploration areas of the slope, and can fully reflect the engineering geological problems of the exploration areas. The summary analysis of the above application results is shown in figure 9, and the analysis conclusion can be drawn as follows:

1. There is a fault structure running through the integral slope on the west side of the pit, which is in a north-south direction, cutting off the western slope, which has a great impact on the overall stability of the slope. In the northwest and the southwest faults are located on the outside of the pit. In the central part of the west side of the pit, the fault is located inside the pit. But with the slope excavation, the fault will intersect with the slope at the bottom, which is not conducive to the slope stability.
2. There are fault structures in the western part of the pit. The starting point of development is in the central part of the west side of the pit and the eastern side of the gully. And it develops to the inner part of the mine, about 600 meters deep.
3. The width and depth of the middle structure of the pit is large, and there are two groups of large structures, among which the secondary structure is concluded to be more developed. And the fault is a water-rich region, which is very unfavorable to the overall stability of the slope.

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