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Study on induced polarization method based on differential transformation in karst area survey

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Objectives

In order to rationally develop and utilize groundwater resources and give full play to their resource advantages, it is necessary to carry out the exploration of groundwater resources. Due to the strong dissolution in karst areas, the development of karst landforms, atmospheric precipitation is easy to penetrate into groundwater, and the lack of surface water causes drought, so finding groundwater has become an important problem faced by karst areas.In this study, the dam axis of a dam site in Huaping County, Lijiang City was investigated using the induced polarization method. The application of polarization rate and half-life as characteristic parameters was introduced to determine the underground water level, karst development, and fault structure in karst regions. To improve the reliability of the survey results and reduce interference from complex geological conditions, a method of differentiating the resistivity curve through approximation with a 6th-degree polynomial or a logarithmic polynomial was proposed. The method was validated using drilling data in combination with previous geological survey data, and the results of graphical analysis and interpretation of multiple parameters were used to determine the underground water level, karst development, and fault structure in the dam axis exploration area. The results indicate that the excitation polarization method is an effective means to find groundwater in karst areas, and the changes of apparent resistivity, polarizability and half-decay are closely related to the enrichment, karst development and fault structure of groundwater,the method of differentiating the resistivity curve through approximation with a logarithmic polynomial is more effective than approximation with a 6th-degree polynomial in the investigation of dam sites.The search for groundwater, karst development, and fault tectonics in future karst areas provides new ways to process data.At the same time, improving the efficiency and accuracy of welling.The structural map and measuring point layout of the exploration area are shown in Fig.1.

Methods

Principle of differential transformation method

1) Differential transformation method for calculating effective interval resistivity

Assuming that the depth function $\rho_e(h)$of the average resistivity is known, the dependence of the average longitudinal resistivity on the depth in the geoelectric profile can be expressed as :

$$\rho_e(h) = \frac{h}{S(h)} \qquad (1)$$

Here, $S(h)$ is the depth function of the total longitudinal conductivity.

The integral transformation of the depth 0 ~ h to the relation (1) is carried out.

$$S(h) = \int_0^h \frac{1}{\rho(h)} dh \qquad (2)$$

The differential transformation of the left and right parts of the relation (1) is carried out at the depth h.

$$\frac{d\rho_e}{dh} = \frac{S - h\frac{\partial S}{\partial h}}{S^2} = \frac{1}{S} - \frac{1}{S}\cdot\frac{h}{S}\cdot\frac{1}{\rho(h)} = \frac{1}{S}\left(1 - \frac{\rho_e(h)}{\rho(h)}\right) \qquad (3)$$

$\rho(h) = \frac{\partial h}{\partial S}$ is the longitudinal resistivity at depth h (the actual resistivity of rock within depth h).

$$S\frac{d\rho_e}{dh} = \left(1 - \frac{\rho_e(h)}{\rho(h)}\right) \qquad (4)$$

$$\frac{\rho_e(h)}{\rho(h)} = 1 - S\frac{d\rho_e}{dh} \qquad (5)$$

$$\rho(h) = \frac{\rho_e(h)}{1 - S\frac{d\rho_e}{dh}} = \frac{\rho_e(h)}{1 - \frac{h}{\rho_e(h)}\frac{d\rho_e}{dh}} \qquad (6)$$

The practical experience of electrical sounding shows that the corresponding relationship between the real depth and the effective depth of the study is $AB/3 = h_{ef}$, Let $\rho_e = \rho_k$, then

$$\rho_{ef}(h_{ef}) = \frac{\rho_k(h_{ef}))}{1 - \frac{h_{ef}}{\rho_k}\frac{d\rho_k}{dh_{ef}}} \qquad (7)$$

ρ_{ef}-Effective interval resistivity;ρ_k-Apparent resistivity

In practice, the sounding curve $\rho_k(AB/3)$ can be regarded as a dependence of the apparent (effective) average longitudinal resistivity on the effective depth $AB/3 = h_{ef}$.

2) 6-order polynomial and logarithmic polynomial approximation apparent resistivity sounding curve

The actual exploration is carried out under complex geophysical and geological conditions. There are many near-surface unevenness, uneven terrain, complex vegetation and other interference factors, resulting in quite distorted sounding curves in many cases, which makes their research complicated. In order to realize the differential transformation, it is proposed for the first time to approximate the apparent resistivity sounding curve by linear polynomial and logarithmic polynomial.

6-order polynomial:

$$\rho_k = a + b\rho_k + c\rho_k^2 + d\rho_k^3 + e\rho_k^4 + f\rho_k^5 + g\rho_k^6 \qquad (8)$$

logarithmic polynomial:

$$ln\rho_k = a + bln\rho_k + c(ln\rho_k)^2 + d(ln\rho_k)^3 + e(ln\rho_k)^4 + f(ln\rho_k)^5 + g(ln\rho_k)^6 \qquad (9)$$

Using logarithmic polynomial approximation, on the one hand, the curve image on the logarithmic scale is smoother, and on the other hand, it is easier to solve in the area with smaller spacing.

In the differential transformation (7) algorithm, the logarithmic derivative is used to calculate the derivative $\frac{\partial\rho_k}{\partial h_{ef}}$, mainly considering the same approximate value as the logarithmic polynomial curve. The use of logarithmic derivative transforms the algorithm of differential transform (7) into (13) :

$$ln\rho_k = f(lnh_{ef}) \qquad (10)$$

$$\frac{dln\rho_k}{dlnh_{ef}} = \frac{\frac{1}{\rho_k}\cdot\frac{\partial\rho_k}{\partial h_{ef}}dh_{ef}}{\frac{1}{h_{ef}}dh_{ef}} = \frac{h_{ef}}{\rho_k}\frac{\partial\rho_k}{\partial h_{ef}} \qquad (11)$$

$$\frac{\partial\rho_k}{\partial h_{ef}} = \frac{\rho_k}{h_{ef}}\frac{dln\rho_k}{dlnh_{ef}} = \frac{\rho_k}{h_{ef}}\frac{ln(\rho_{ki+1}/\rho_{ki})}{ln(h_{efi+1}/h_{efi})} \qquad (12)$$

$$\rho_{ef}(h_{ef}) = \frac{\rho_k(h_{ef})}{1 - \frac{ln(\rho_{ki+1}/\rho_{ki})}{ln(h_{efi+1}/h_{efi})}} \qquad (13)$$

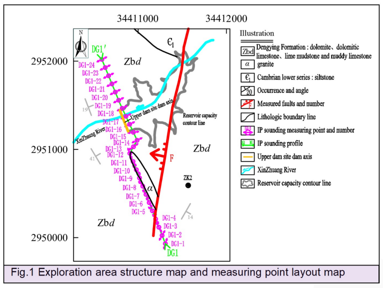
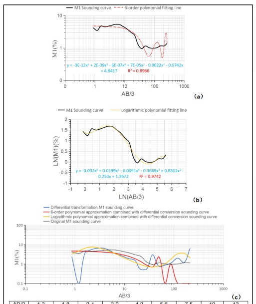


Fig.1 Exploration area structure map and measuring point layout map

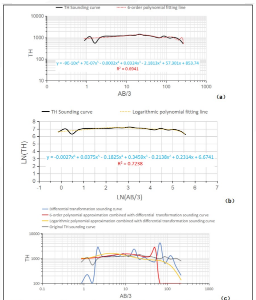
Results

An application example of induced polarization method exploration is carried out in the dam axis of a reservoir in Huaping County, Lijiang City.The exploration area is mainly composed of light gray, deep gray, gray-white dolomite, dolomitic limestone,lime mudstone and muddy limestone in the Upper Sinian Dengying Formation (Zbd). The intrusive rock α is exposed on the right bank slope of the upper dam site, and the lithology is granite.The principle of geophysical characteristics determination : groundwater enrichment is high half time, high degree of decay, high polarizability and low resistance ; the karst development and fault are low resistance, the difference is that the low resistance of karst development is local block, and the low resistance of fault has obvious characteristics of breaking off the adjacent sides.The half time(TH), polarizability(M_1) and apparent resistivity(ρ_k) parameters of sounding points DG1-1 ~ DG1-24 are calculated by differential transformation method combined with sixth-order polynomial and logarithmic polynomial approximation. Taking DG1-6 as an example, see Figure 2~4.



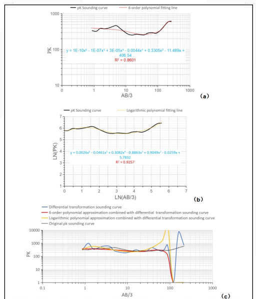
AB/2	1.3	1.8	2.4	3.2	4.2	5.6	7.5	10	13
MN/2					0.5				
AB/2	10	13	18	24	32	42	56	75	100
MN/2					3				
AB/2	75	100	130	180	240	320	400		
MN/2					30				

Fig.2 : sounding point DG1-6 (a) 6-order polynomial fitting ; (b) Logarithmic polynomial fitting ; (c) The polarizability(M1) sounding curve of the sounding point DG1-6 is calculated by the differential transformation method combined with the sixth-order polynomial and logarithmic polynomial approximation. X-axis unit : m; Y-axis unit : %



AB/2	1.3	1.8	2.4	3.2	4.2	5.6	7.5	10	13
MN/2					0.5				
AB/2	10	13	18	24	32	42	56	75	100
MN/2					3				
AB/2	75	100	130	180	240	320	400		
MN/2					30				

Fig.3 : sounding point DG1-6 (a) 6-order polynomial fitting ; (b) Logarithmic polynomial fitting ; (c) The half time(TH) sounding curve of the sounding point DG1-6 is calculated by the differential transformation method combined with the sixth-order polynomial and logarithmic polynomial approximation. X-axis unit : m; Y-axis unit : ms



AB/2	1.3	1.8	2.4	3.2	4.2	5.6	7.5	10	13
MN/2					0.5				
AB/2	10	13	18	24	32	42	56	75	100
MN/2					3				
AB/2	75	100	130	180	240	320	400		
MN/2					30				

Fig.4 : sounding point DG1-6 (a) 6-order polynomial fitting ; (b) Logarithmic polynomial fitting ; (c) The apparent resistivity(ρk) sounding curve of the sounding point DG1-6 is calculated by the differential transformation method combined with the sixth-order polynomial and logarithmic polynomial approximation.X-axis unit : m; Y-axis unit : Ω·m

1) It can be seen from Figure 2~4 that the sounding curve of logarithmic polynomial approximation half time(TH), polarizability(M_1) and apparent resistivity(ρ_k) parameters is better than that of 6-order polynomial, and the correlation coefficient is closer to 1, which can more accurately reflect the change of field measured sounding curve and reduce the sudden change point caused by external interference.

2) It can be seen from the figure 4 that the differential transformation method has a certain amplification effect on the sounding curve, especially on the double logarithmic coordinates TH, M_1, ρ_k and AB/3 curves. When the TH, M_1, ρ_k curves rise, the TH, M_1,ρ_k appear to increase significantly ; when the curves of TH, M_1 and ρ_k decrease, TH, M1, and ρ_k decrease significantly, or even decrease to a negative value.

3) By analyzing the half time(TH), polarizability(M_1) and apparent resistivity(ρ_k) sounding curves obtained by DG1-1 ~ DG1-24 ' differential transformation method combined with logarithmic polynomial approximation, the groundwater enrichment degree, karst development status and spatial location of fault structure in the exploration area of the dam axis of the upper dam site are inferred, as shown in Figure 5.

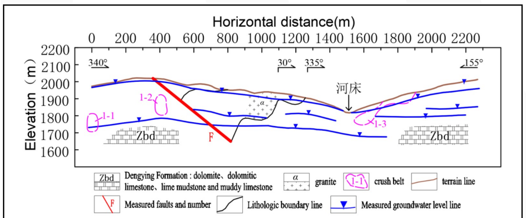


Fig.5 DG1-DG1' section interpretation diagram of a reservoir project in Lijiang City

Conclusions

1. The differential transformation method has an amplification effect on the abnormal value of the sounding curve and effectively highlights the abnormal space position. At the same time, it is concluded that the differential transformation after the logarithmic polynomial approximation of the sounding curve is the best data processing method.

2. By analyzing the enlarged abnormal values, it is easier to determine the groundwater enrichment degree, karst development status and spatial location of fault structure in the exploration area of the dam axis at the upper dam site. The logarithmic polynomial approximation sounding curve and then the differential conversion method have guiding significance for the location of boreholes, and have certain feasibility in the investigation of reservoir dam site.

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