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Forward study of complex resistivity on chromium slag contaminated site model

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ABSTRACT

The complex resistivity method is used as the detection method to investigate into the chromium concentration of chromium slag contaminated site. Cole–Cole model is confirmed to be used as the model of the relationship between the chromium concentration, water content as well as other soil's physical parameters and the complex resistivity. Before the detection on the actual site, the simulation model on the pollution site should also be setup to verify the accuracy of forward and inverse calculation. The paper focused on forward calculation. Based on the investigation data of the typical chromium slag contaminated site, the forward calculation model was set up. Based on dipole–dipole equipment, the apparent complex resistivity with multiple frequency points was obtained. Thus, this paper analyzed how the site model's physical parameters and Cole–Cole's parameters affected the apparent complex resistivity.

Keywords: Chromium-contaminated soil; Forward calculation; Cole–Cole model; Water content; Chromium concentration

1. Introduction

In recent years, the soil pollution problem has been increasingly deteriorated in China, especially the soil pollution caused by heavy metal. In terms of the restoration of polluted site and related treatment projects, the previous work carried out is clarifying the degree of pollution, the scope of pollution and the conditions of site, etc. However, the traditional detection methods on the contaminated site mainly adopted the exploring drill to take samples and combine with indoor chemical analysis, which were time-consuming and expensive. Due to the restrictions in terms of fees and other factors, it has been becoming an urgent technological problem to find a new rapid and accurate method [1]. In the past several years, environmental practitioners have combined geophysical prospecting and traditional chemical detection, and applied them into the exploration for contaminated sites [2].

The paper studied the principle of the detection method on the site polluted by heavy metal, the physical parameters of soil and the effects on the measurement parameters of soil, analyzed the relationship between the physical parameters of soil polluted by typical heavy metals, such as chromium. Moreover, the model of mathematical relationship was set up to form the soil resistivity features response theory of geophysical pollution prospecting and the basis was provided for explaining other geophysical prospecting technology [3,4].

The work that has been done at the early stage: experimental research on the electric features of the soil polluted by chromium, finding out the soil sample with the same

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resistivity, and recognizing the difference of the amplitudes of complex resistivity, which laid the experimental foundation for evaluating the actual polluted site [5]. It was shown that the amplitude of chromium contamination soil complex resistivity is decreasing with increasing frequency according to measured results at different moisture content, chromium content, and porosity [6]. With the theoretical foundation of the complex resistivity property of the soil polluted by chromium, the Cole–Cole model as the circuit model was chose, the relationship between the circuit model's parameters and soil's physical model's parameters in the microstructure was deducted, the inversion calculation method of Cole–Cole model's parameters of soil polluted by chromium was made [7], and the optimal tools to obtain partial soil parameters based on some measurement data and direct calculation of finite elements of the simulated site polluted by chromium was adopted.

The paper focused on direct calculation. Based on the investigation data of the typical site polluted by chromium slag, the paper set up the site model. In the complex resistivity method, AC point power supply was used. One-dimensional digital filtering method was adopted to obtain the distribution of ground electric potential and apparent complex resistivity. Besides, the paper analyzed the physical parameters of the site model (water content and pollution content) and the pattern of effects on apparent complex resistivity exerted by the change of Cole–Cole parameter.

2. Establishment of model of site polluted by chromium slag

The prerequisite of the simulation of numerical value is the establishment of model. First of all, field investigation should be carried out on the actual site polluted by chromium slag. Based on the information of drilling hole, the paper analyzed the water content on the site, pollution content and depth, and the distribution of soil layers and other features. Then, the paper concluded the pattern.

- The feature of the distribution of the content of chromium pollution: being the highest content close to the pollution source, dispersion in the vertical and horizontal direction with obvious boundary; however, in partial vertical direction, there occurred the phenomenon of the increase of pollution content.
- The change of water content is not obvious in the horizontal direction and increases in the vertical direction.
- In the soil distribution, the surface soil is loess soil with the thickness of 0–1 m. The lower part is sand with the thickness of about 20 m.

Liu [7] deducted the relationship between the circuit parameter and the soil's physical parameters. Here, we use Cole–Cole formula to transform the content of pollutants, water content, and other soil physical parameters to the parameters in the circuit model, such as resistivity:

$$\rho = \rho_0 \left[1 - m \left(1 - \frac{1}{1 + \left(i\omega\tau \right)^c} \right) \right] \quad (1)$$

Considering the convenience, in the site model, CR1 Dmod program is used temporarily to replace the finite element method [8]. CR1 Dmod is a forward modelling code in MATLAB, capable of handling several commonly used electrical and electromagnetic methods in a 1D environment. Nevertheless, the CR1 Dmod routinely handles complex resistivity and offers solutions based on the full electromagnetic equations as well as the quasi-static approximation.

In the program, the horizontal semi-spatial model and horizontal two-layer media model are set to calculate the numerical value. Besides, Cole–Cole complex resistivity model is introduced. Dipole–Dipole equipment is used as the measurement equipment shown in Fig. 1. AB is the power supply terminal. CD is the measurement terminal. AB = BC = CD = 20 m.

In the evenly distributed semi-space, we change water content, content of chromium pollution, charging rate, and frequency factor to observe the pattern of change of simulation results. In the horizontal two-layer media, we change the depth of pollution on the upper part to observe the pattern of change of simulation result. The section of the simulation drawing is shown in Fig. 2.

3. Effects of parameters of site physical model on the apparent resistivity

3.1. Frequency domain response of even semi-space model

First of all, the measurement data of the even semi-space site model under different frequencies are provided. From Fig. 3, it can be seen that water content greatly affects the amplitude. When the water content is low, dispersion characteristics are quite strong. With the increase of water content, the amplitude decreases. When the water content is high, there are no obvious dispersion characteristics. In the change of the phase angle, we can see that the two models have no obvious differences in the low frequency. In the high frequency, high water content displays larger phase angle.

From Fig. 4, it can be seen that the effects of pollution content on the amplitude of complex resistivity are similar to the effects of water content. Under the situation of pollution content, there are certain dispersion characteristics. With the increase of pollution content, the amplitude decreases. Under the situation of high pollution content, there are no obvious dispersion characteristics. At low frequency, the phase angle does not have obvious differences. At high frequency, the low pollution frequency has a larger phase angle.

Fig. 5 shows the effects of different charging rates *m* on the apparent complex resistivity. The higher the charging rate is, the stronger dispersion characteristics the amplitude and phase angle of apparent complex resistivity demonstrates.

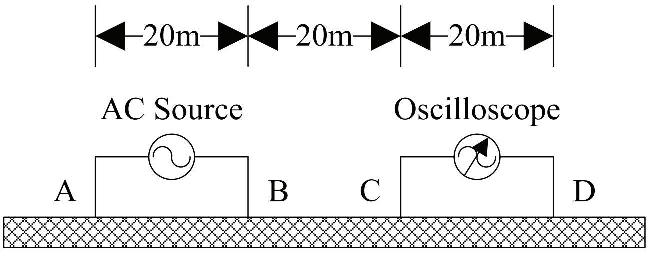


Fig. 1. Dipole–Dipole device.

Fig. 6 shows the pattern of the effects of different frequency factors *c* on the apparent complex resistivity. The increase of the numerical value of *c* enhances the dispersion characteristics of the amplitude of resistivity. At the same time, the phase angle has the maximal and minimal value at partial positions.

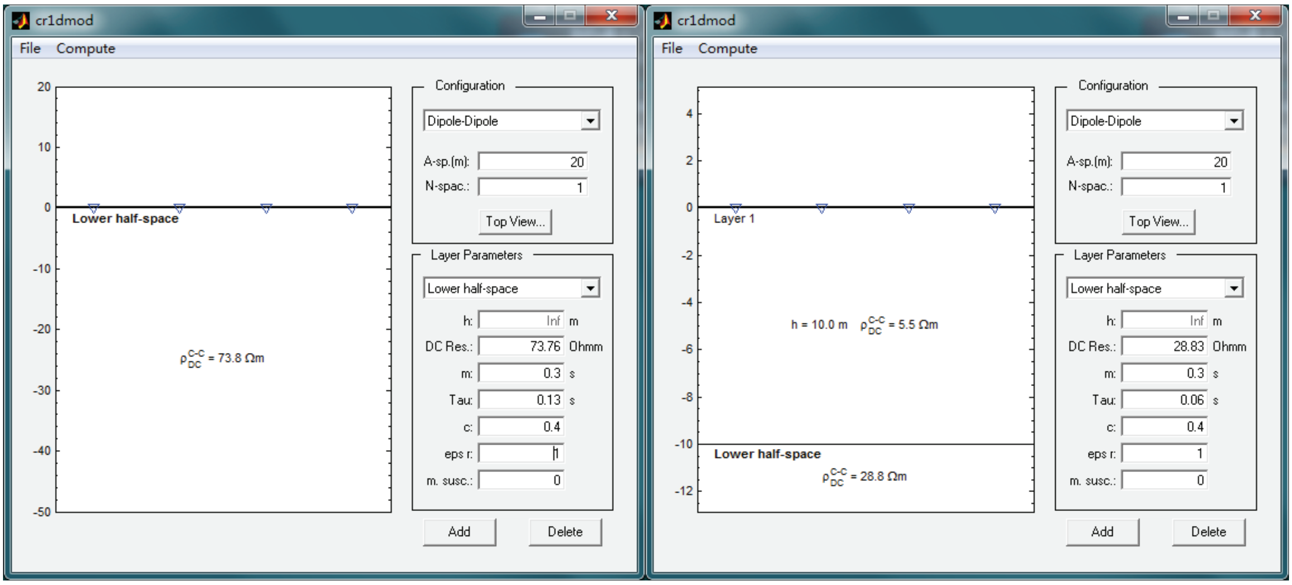
3.2. Frequency domain response of horizontal two-layer media model

The paper sets up the horizontal two-layer media model to analyze the pattern of effects of different pollution contents on measurement of apparent complex resistivity. From Fig. 7, we can see that with the increase of the pollution content, due to the increase of ion components in the soil, the amplitude of apparent complex resistivity is decreased obviously. It is helpful for the qualitative evaluation on the polluted site. However, for the phase angle, the increase of the pollution depth does not bring obvious differences. The application of the phase angle data thus deducted is limited to a certain degree.

4. Conclusion

On the basis of aforementioned achievements, this paper carries out direct calculation of the model of the site polluted by chromium slag based on the complex resistivity method.

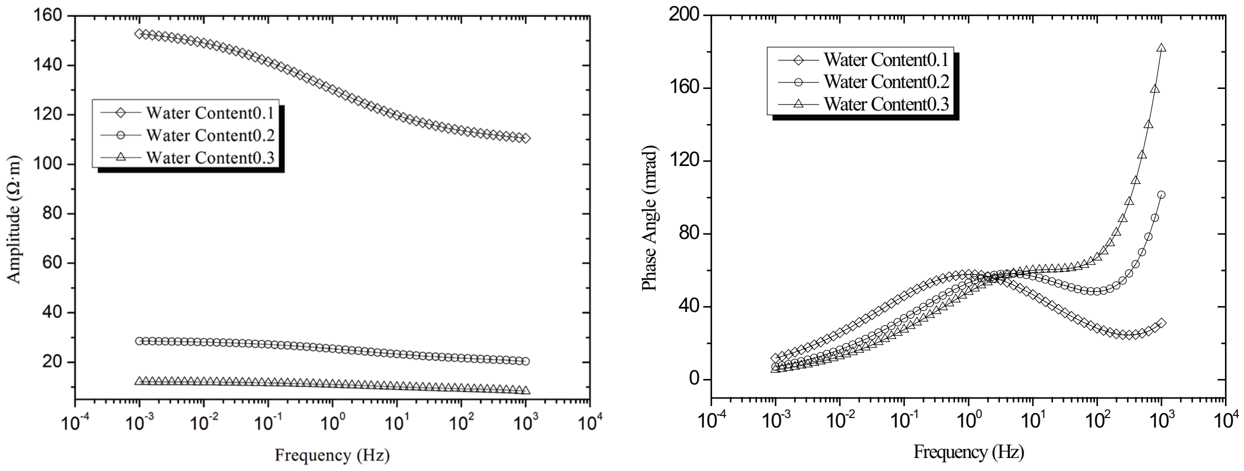
- The typical site polluted by chromium slag is selected for investigation. Based on the information of drilling hole, the paper analyses and concludes the water content on



Dipole-Dipole
A-sp.(m): 20
N-spac.: 1
Lower half-space
h: Inf m
DC Res.: 73.76 Ohmm
m: 0.3 s
Tau: 0.13 s
c: 0.4
eps r: 1
m. susc.: 0

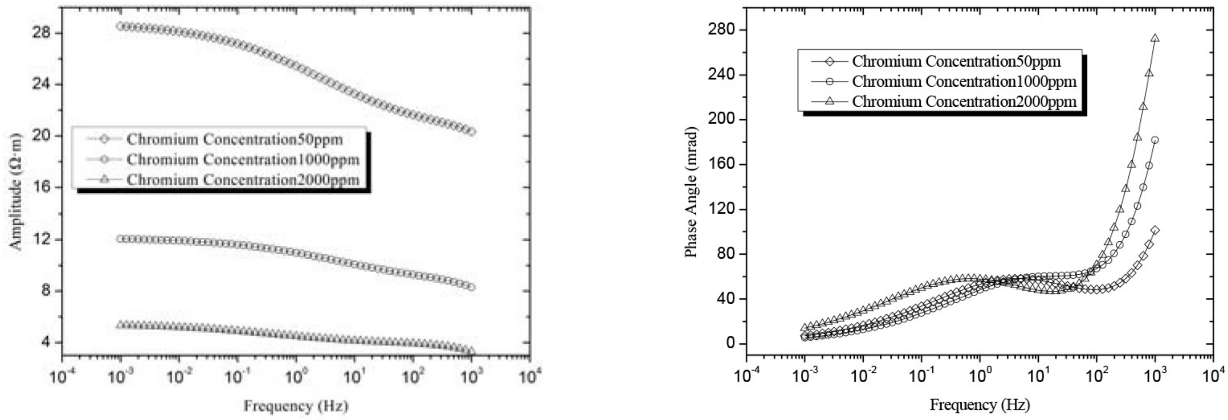
Dipole-Dipole
A-sp.(m): 20
N-spac.: 1
Lower half-space
h: Inf m
DC Res.: 28.83 Ohmm
m: 0.3 s
Tau: 0.06 s
c: 0.4
eps r: 1
m. susc.: 0

Fig. 2. Screenshot of simulation results.



(a) amplitude (b) phase angle

Fig. 3. Complex resistivity with different water content. (a) Amplitude and (b) phase angle. Field site model: water content 0.1, 0.25, and 0.4; chrome concentration 50 ppm. Cole–Cole model: ρ = 73.76473725, 28.83397018, and 12.14955737; τ = 0.13157, 0.061149, and 0.030214; *m* = 0.3; *c* = 0.4.



(a) amplitude (b) phase angle

Fig. 4. Complex resistivity with different pollution concentration. (a) Amplitude and (b) phase angle. Field site model: water content 0.25; chrome concentration 50, 1,000, and 2,000 ppm. Cole–Cole model: $\rho = 28.83397018$, 7.466221777, and 5.461693531; $\tau = 0.061149$, 0.27347, and 0.38674; $m = 0.3$; $c = 0.4$.

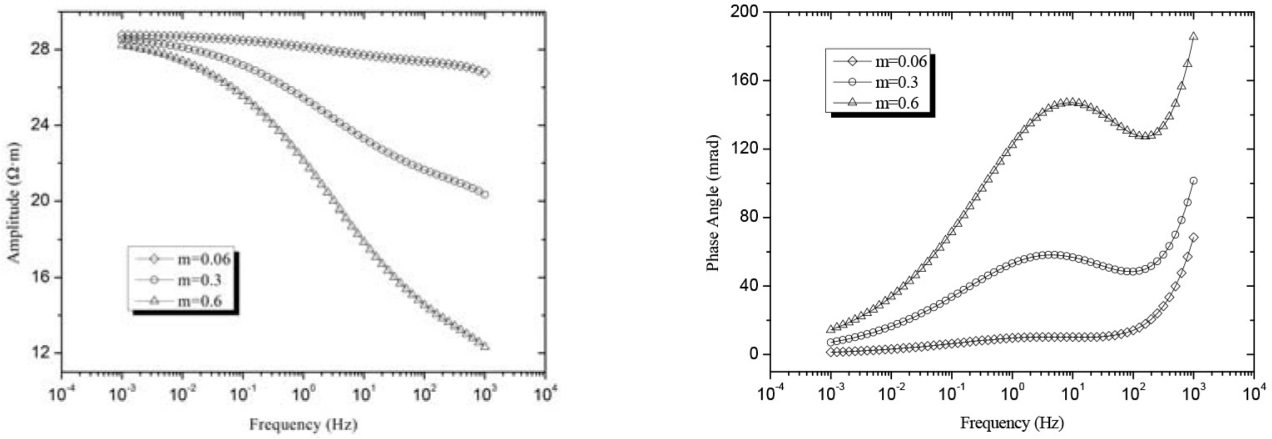
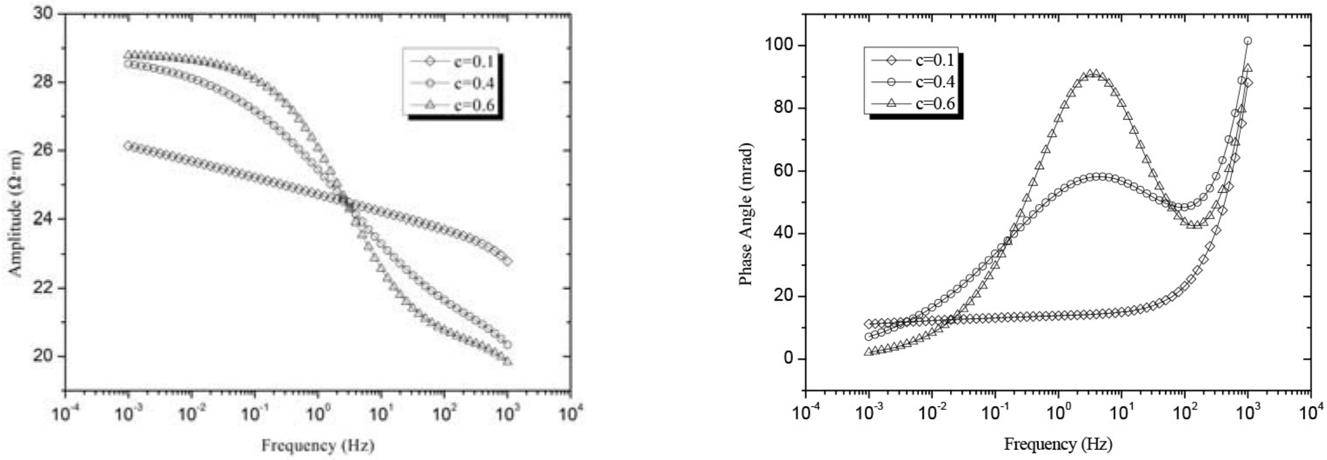


Fig. 5. Complex resistivity with different charge rate. Field site model: water content 0.25, chrome concentration 50 ppm. Cole–Cole model: $\rho = 28.83397018$; $\tau = 0.061149$; $m = 0.02$, 0.3, and 0.6; $c = 0.4$.



(a) amplitude (b) phase angle

Fig. 6. Complex resistivity with different frequency factor. (a) Amplitude and (b) phase angle. Field site model: water content 0.25, chrome concentration 50 ppm. Cole–Cole model: $\rho = 28.83397018$; $\tau = 0.061149$; $m = 0.3$; $c = 0.1$, 0.4, and 0.6.

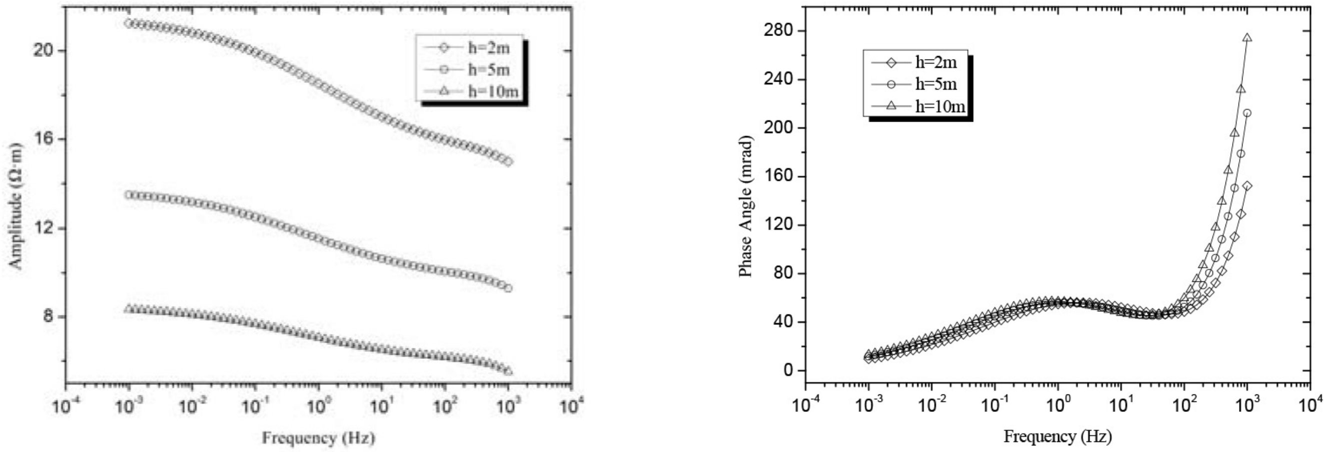


Fig. 7. Complex resistivity with different pollution depth. Field site model: upper space thickness 2, 5, and 10 m; chrome concentration 2,000 ppm. Whole field: water content 0.25, chrome concentration 50 ppm. Cole–Cole model: upper space $\rho = 5.461693531$, $\tau = 0.38674$, $m = 0.3$, $c = 0.4$. Lower space $\rho = 28.83397018$, $\tau = 0.061149$, $m = 0.3$, $c = 0.4$.

the site, pollution content and depth, and the distribution of soil layers and other features. It is found that chromium slag disperses in the horizontal and vertical direction with an obvious boundary. The water content increases with the increase of the depth. The soil is mainly composed of sand. Factual basis is provided for the establishment of the model.

- The even semi-space model and horizontal two-layer model are set up. This paper observes the pattern of effects on the measured apparent complex resistivity exerted by the change of physical parameters of the site's soil. In the study on the amplitude and phase position, it is found that amplitude is a parameter relatively sensitive to the change of soil's physical parameters.

This paper lays a solid foundation for subsequent work, including amplitude measurement based on complex resistivity, and inverse calculation of important physical parameters of the soil, that is, calculation of pollution content and water content.

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