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Technology and Application of Transient Electromagnetic Detection of Overlapping Loop

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Abstract. In the case of a certain geoelectric section, we analyze the diffusion depth of TEM field, and simulate the time when the peak of electric field excited by different coils emitting step pulses reaches a certain depth underground, all of which indicate that the arrival depth of TEM diffusion field is only related to the delay time. This lays a theoretical foundation for the TEM method of small center loop to detect greater depth. If the equivalent sending current of transmitter and the equivalent area of receiving coil or probe are increased, the TEM method of small loop device can reach the detection depth equivalent to that of large loop device in a certain range. This paper tries to demonstrate the detection ability of small center loop method from the combination of theory and practice.

Keywords. Transient electromagnetic field, small loop, detection ability

1. Introduction

The argument of using the transient electromagnetic (TEM) method with small concentric loop device to detect greater depth has been discussed in relevant conferences [1-3]. Spies (1989) [4] pointed out in his classic paper on the depth of electromagnetic method that the time or frequency of electromagnetic (EM) response of a deep inhomogeneous body just detected depends on: (1) the buried depth of the inhomogeneous body; (2) Average resistivity of the upper section; (3) The relationship with the form of source, the way of receiving and the distance between them are relatively small. In this paper, we further confirm the guiding significance of the theory combined with the practice, and show the detection ability and effect of TEM method of small center loop device.

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2. Explore Theories

2.1. Analytical Calculation

The detection depth of TEM method is defined by the quasi-stable electric field formula excited by step pulse in a uniform all-space conductive medium [5-6].

$$e_x = -\frac{I}{2}\sqrt{\frac{\mu_0}{\pi\sigma_1 t}}\exp\left(-\frac{\mu_0\sigma_1}{4t}z^2\right)u(t) \tag{1}$$

Where, t is the observation time, and μ_0, σ_1 are the magnetic permeability (assuming the earth is nonmagnetic) and electrical conductivity of the earth, and z is the distance from the field point to the source point. Keep z in formula (1) constant, and make its derivative with respect to time equal to zero to obtain the formula:

$$\delta_{\mathrm{TD}} = \sqrt{\frac{2t}{\mu_0\sigma_1}} \tag{2}$$

δ_{TD} is the depth at which the peak of the step pulse reaches at a given time, as shown in figure 1.

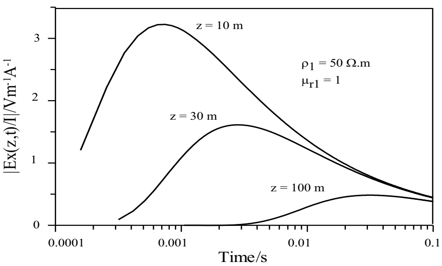
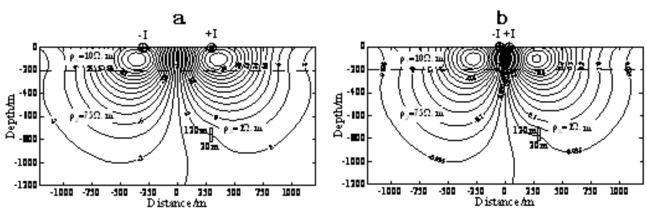


Figure 1. Transient responses of a step pulse at various distances (ρ_1 = 50 Ω.m, μ_{r1} = 1, ε_{r1} = 15).

It can be seen from formula (2) that the diffusion depth of transient electromagnetic field is only related to the delay time when the stratum is determined, which can also be verified from the following simulation results.

2.2. Numerical Simulation



(a) 600m (b) 10m

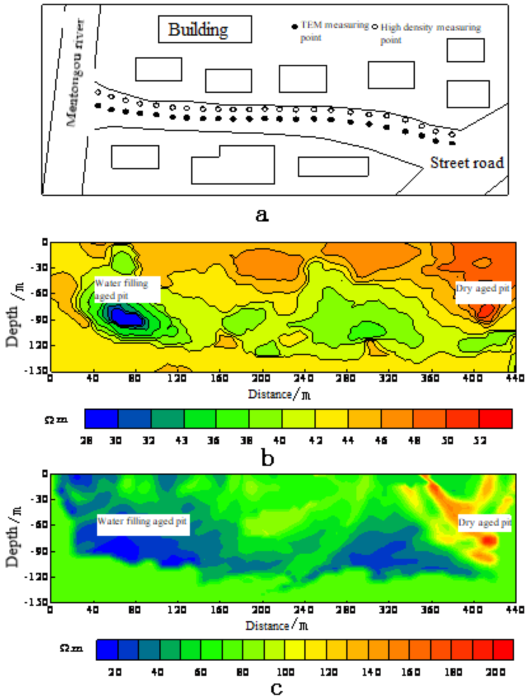
Figure 2. Transient electric contour for different size loops.

Figures 2(a) and 2(b) are the calculation results of two-dimensional finite difference simulation of different sizes of transmitting coils. In figure 2(a), the distance between -*I* and +*I* is 600 m, and in figure 2(b), the distance between -*I* and +*I* is 10 m. It can be seen from the comparison that the depth reached by the field in the same time has nothing to do with the loop size. However, the signal intensity of the big loop is large, which is conducive to observation and belongs to the problem condition, which can be changed and created. In order to solve this problem, such as increasing the equivalent sending current of the transmitter and the equivalent area of the receiving coil or probe, and ensuring that there are enough secondary field attenuation signals available for acquisition from these two aspects, the detection depth can be realized. In a certain range, the TEM method of small loop device can reach the same detection depth as that of large loop device.

3. Test Results

In the early 1990s, the small center loop was used for detection. Due to the task of detecting the old kiln in Mentougou District, Beijing, and the restrictions of dense buildings on the ground and strong interference sources, the conventional transient electromagnetic method could not be used for construction, so it was not allowed to test the TEM method with large power supply current and small center loop, and a single square wire frame of 5×5 m^2 was used for power supply with a current of 100 A; The equivalent area of receiving magnetic probe is 2500 m^2. The data interpretation results are shown in figure 2 of the comparison section between high-resolution electrical method and TEM method.

As can be seen from figure 3, the apparent resistivity-depth profiles obtained from the corresponding points on the road in the same street are basically consistent, and the explanation of a flushing water and a dry and old kiln is very good, both of which are about 80 m underground, and are recognized by Party A. We combine the two construction methods, comprehensively interpret the results, and the results are verified by Party A's drilling, the success rate is 80%, which is very ideal. This strengthens the confidence of adopting TEM method with small loop and large current later. On the basis of further research on the detection depth of TEM method [7], according to the idea of increasing the equivalent current of the transmitting coil and the equivalent area of the receiving probe, we use the central small loop TEM device to detect the old kiln, burning area, engineering and hydrogeology in coal mines, all of which achieve good geological results and are extended to other units.



(a) Construction layout; (b) Apparent resistivity-apparent depth profile of high density electrical method; (c) TEM apparent resistivity-apparent depth profile

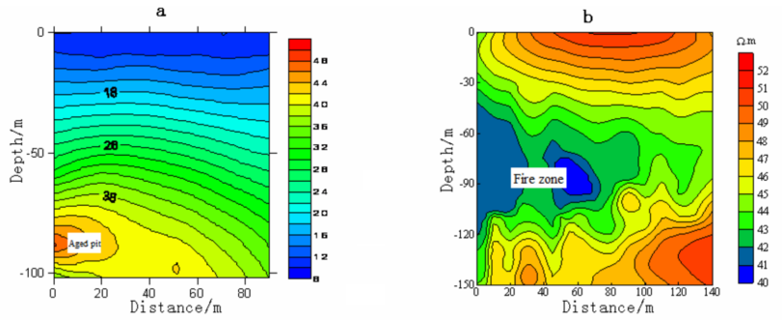
Figure 3. Detect contrast profile of the high resolution method and transient electromagnetic method.

Here are a few examples to show the general situation.

4. Application Renderings

4.1. Effect of Detecting old Kiln and Fire Area on the Ground

In a coal mining area in Xinjiang, we use TEM central loop method to construct according to the transmission wire frame of 5×5 m^2, the transmission current of 120 A and the equivalent area of the probe of 2500 m^2. The task is to detect the old kiln and the burning area within the depth of 200 m. The detection effect is good. Now, two cross-sections in figure 4 are shown, and the abnormal position explained is marked on the figure.

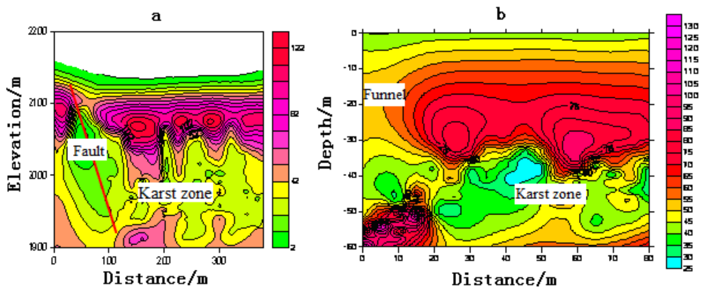


(a) Old kiln (b) Fire area

Figure 4. TEM detection profile of the goaf and fire zone in Xinjiang.

4.2. Ground Detection Karst Effect

To detect karst on a highway slope in Yunnan, TEM central loop method with 5×5 m^2 emission wire frame, 120 A emission current and 2500 m^2 probe equivalent area are still used. The detection effect is obvious, and it can be seen from figure 5 that faults and karst development zones are clearly displayed.



(a) Karst with fault (b) Karst and funnel

Figure 5. Somewhere in Yunnan TEM detection karst profile.

4.3. Water Detection Effect

Because the TEM method of small central loop is adopted, it is very convenient to construct on the water, as long as the device is fixed on the wooden bow and observed according to the point. Figure 6 is the TEM apparent resistivity profile continuously observed on water and land. The device used is the same as before, only the emission current is increased to 150 A. The abnormal signs shown in figure 6 are on the map, reflecting karst areas.

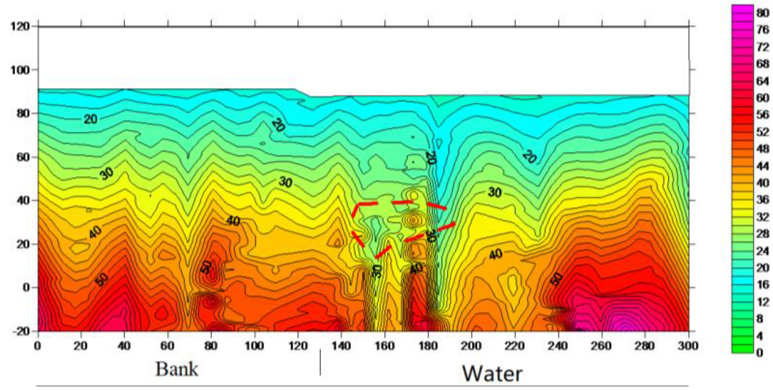


Figure 6. Somewhere in Hunan TEM detection karst profile.

4.4. Underground Water Exploration Effect

Due to the limited space in coal mine, only the small loop TEM method can be used for detection, specifically using the overlapping wireframe of sending and receiving, with a side length of 1.5 m, 10 circles for the former and 25 circles for the latter. The two measured sections are shown as follows.

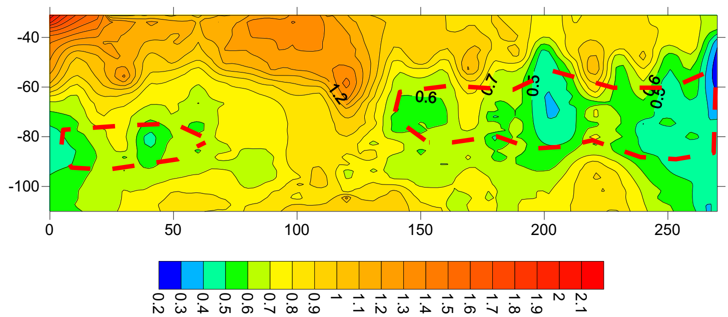


Figure 7. TEM apparent resistivity profile of a coal mine tunnel side.

The figure 7 shows the TEM apparent resistivity map of the side wall of a coal mine roadway. According to the relatively low resistance area of contour color block distribution of the apparent resistivity, the water-bearing zone is outlined, which is confirmed by mining.

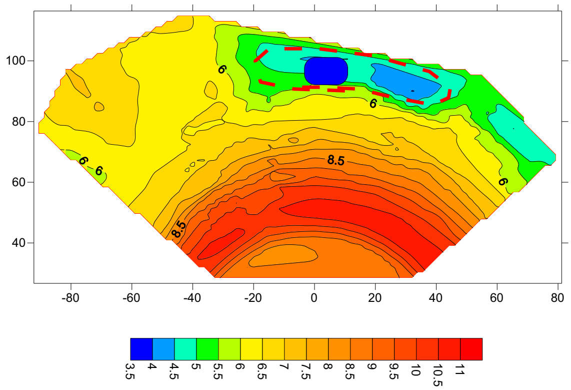


Figure 8. TEM apparent resistivity profile of a coal mine tunnel ahead.

The figure 8 shows the TEM apparent resistivity profile in front of the digging head of a coal mine. According to the relatively low resistance area of contour color block distribution of the apparent resistivity, the water-bearing zone is delineated, which is revealed by the digging.

5. Summary

The detection depth of TEM method is mainly determined by the delay time. When the equivalent current of the transmitting coil and the equivalent area of the receiving probe are increased, the TEM signal intensity of the small transmitting loop device can be compared with that of the large loop device, and the purpose of detecting a larger depth can also be achieved.

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