Application of Transient Electromagnetic Method in saturation region detection in tailings dam

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***Abstract*—Since the 1950 s, Taolin ore has been exploited. Almost a hundred tons of tailing were backfilled between the hills for a long time, which formed Taolin dam during 50 years backfilling deposition. The stability of the huge dam is of great importance for the local people's life and property protection. The transient electromagnetic method has been widely used in engineering survey, it provides kinds of configurations, can meet the demand of survey area with complex terrain.**

In this paper, TEM application is discussed in the detection field of dam saturation region. Firstly, this paper introduces the basic principle of transient electromagnetic method to detect saturation region. In the Multi-channel voltage profile in time domain and the apparent resistivity proposed cross-section diagram, there is obviously anomaly "High voltage- low resistance" in saturation region. Secondly, in order to highlight the vertical profile resistivity change, the vertical first derivative of the apparent resistivity cross-section is calculated. In the apparent resistivity vertical derivative anomaly map, the top of saturation region shows minimum negative gradient anomalies. The size of layers are clearly divided. The results shows that saturation region is almost below the horizontal plane, safe height, which provides reliable geological theory basis for Taolin tailings dam safety evaluation.

Our results suggest that TEM has high detection accuracy. In the field of groundwater prospecting, transient electromagnetic method can be used as an important tool of prospecting.

Keywords—transient electromagnetic method (tem) ; apparent resistivity; vertical first derivative; dam ' s saturation line formatting

I. INTRODUCTION

Taolin lead-zinc mine, located in Linxiang county Hunan province. Lead-zinc ore body occurs in contact zone between granite and Mesoproterozoic low grade metamorphic rock, it is skarn ore deposits. Since the 1950 s, ore has been exploited. Almost a hundred tons of tailings were backfilled between the hills for a long time, which formed Taolin dam during 50 years backfilling deposition. The amount of reservoir sand in Taolin dam is nearly a billion cubic meters. Small form, large surface area, the accumulation of tailings is easy to flow and collapse, especially in the rainy season. Hidden safe troubles existed in 1990s, high saturation line (the top of saturation region), local area is swamping[1],. After treatment, dam condition has been improved markedly. The distribution of the groundwater, is very important for the safety of the huge dam.

One of the most successful techniques using electro-magnetic response for geological survey is the TEM. Compared with traditional survey, TEM is faster and more efficient, and can give a clear image in the detection of a complex geological structure. TEM has been widely used in hydrogeology, oil surface and borehole data studied. TEM has been widely used in engineering survey[2]. Zhang et al. summarized the application of TEM in the groundwater detection[3]. It provides kinds of configurations, can meet the demand of survey area with complex terrain. Han et al. used TEM in detection of water abundance region in coal mine area, which achieved good results[4]. Wang used TEM to predicate groundwater in tunnel in advance, which proves the validity of TEM on groundwater forecasting[5].

II. THEORETICAL BASIS

The transient electromagnetic method is a time-domain electromagnetic method, which is based on the principle of electromagnetic induction. TEM uses a non-grounded loop or an electrode to send a primary electromagnetic pulse into ground, and observing spatial and temporal distribution of secondary electromagnetic field. Generated by the eddy current caused by the primary pulsed, electromagnetic field in the pulse gap, solving a related geological problems by studying the attenuation law of secondary electromagnetic field[6].

TEM has been used with different configurations such as center loop configuration, the dipole configuration, the large-loop configuration, etc, of which the same point configuration with an effective solution to the record-point problem, is usually used in the engineering field. The same loop configuration, whose transmitter coil and receiver coil are the same set of coil. Coincident loops configuration is showed on Fig. 1(b), whose transmitter coil and receiver coil are two separate sets of coils with same size and overlapping[7].

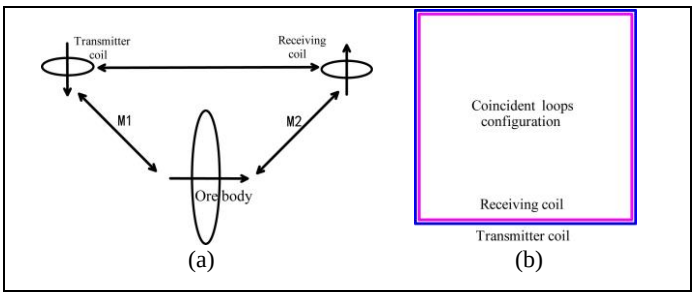

Fig. 1. (a) The map of TEM principle (b) The map of coincident loops configuration

Compared with other devices, the coincident loops configuration device has some advantages. Firstly, this device is better coupling with the conductors of all kinds of shape (except vertical plate) and abnormal amplitude is stronger. Secondly, on the condition of good conductive cap rock or the surrounding rock, the shape of anomaly is easy to analysis. And, characteristics of signal in time domain is stable. Moreover, the penetration depth of this device is deeper[8].

Considering all kinds of factors, we choose the coincident loop configuration in our research. The following formula (1) is used to calculate late apparent resistivity[9].

$$\rho_L = \frac{\mu}{4\pi T}[(2\pi a^2 \mu I) / (5T\frac{\partial B_Z}{\partial T})]^{\frac{2}{3}} \quad (1)$$

I is the emission current, ρ_L represents the apparent resistivity of uniform half space, a is the radius of fire box, μ is the permeability of uniform half space (approximate $4\pi\times10^{-7}$ H m), T is the time, calculated when the current shut off.

The resistivity of water-bearing layer is different from others, which provides a physical basis for distinguishing the changes. Layer filled with water, which causes the resistivity decreasing. Effected with the eluviation, the content of Pb, Zn, Cu, Cr and other heavy metal ions content in groundwater is higher than normal, which is more conductive than normal layers. Li measured several samples of inorganic pollution water[10]. By experiment he found that each reagent resistivity reduced with the increase of concentration of pollutants, but the decreasing speed is different. So the saturation region is characterized by low resistance in cross-section diagram.

TABLE I. HEAVY METAL ELEMENT CONTENTS IN WATER SAMPLES

Item	Pb	As	Zn	Cu	Cr
Water of the eastern dam	/	3.3	/	19	45
Water of the western dam	50	1.1	18	20	50
background value	1.4	1.2	5	1.4	1.64

When electromagnetic field through low resistance strata, the attenuation of secondary eddy current slows down, induction electromotive force is higher[11]. This feature of high induction electromotive force and low resistivity has provided preconditions for the electromagnetic exploration.

III. FIELD WORK METHOD AND DATA PROCESSING

The surveyed area lies in northwest of Linxiang county, the south edge of Yaolu Mountain, which is on the landforms of the typical hilly region in the Jiangnan area. Jiangnan Desert, is 10 km away from downtown, whose sand layer is more than 50 m deep. The amount of reservoir sand is nearly billion cubic meters, and it's the largest artificial desert in central south region of China.

According to the geologic date, the main formation of measured area includes Proterozoic metamorphic rocks of Lengjiahe, Lower Paleozoic neritic faces clastic and carbonate, Cretaceous – Tertiary continental clastic, and Quaternary alluvium. It is a complex structure, and has magmatic intrusion[12].

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A. *Working device and parameters*

CASTEM-R1, the working device in this survey is made by institute of electronics, Chinese academy of sciences, which is Multi-Function Electromagnetic System. The system is one of advanced systems of geology exploration. Combined with the work area geological characteristics, we choose coincide-loop device. Transmit and receive coil are 30 m × 30 m.

The main performance parameters: transmitting periodic time T=40ms, delay time De=2.2us, the sampling time window ranges 1.5us to 7.8ms, superposition times St=256, supply current 7.2A, synchronization mode: GPS synchronization system.

B. *Data processing*

The measured data are archived. Data processing has been done in order to eliminate the effect of environmental noise. The winglink software suit was adopted to process the field data. First of all, the time series should be picked out and mutation points out should be rejected. After data preprocessing, calculate the apparent resistivity. Attenuation curves of magnetic field in the time domain were transferred to the apparent resistivity in time domain and then transferred to the resistivity variation with depth. Finally the apparent resistivity section is completed.

IV. DATA ANALYSIS AND RESULTS

Several lines are measured on tailings dam. One of them distributed from east to west. The measurement results are shown in the images below.

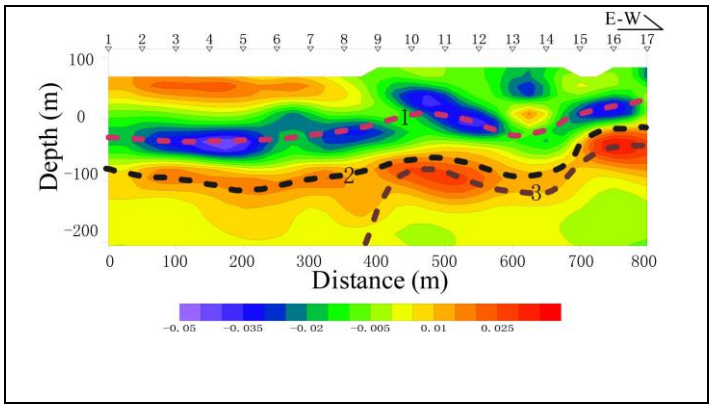

Fig. 2. (a) The Multi-channel voltage profile in time domain of line (b) The apparent resistivity proposed cross-section diagram of line

The Multi-channel voltage profile in time domain of this line is showed in Fig. 2 (a). The value of early V/I is consistent well. The value decay rates changes with time. Ranging from 100-500 m along line, late curve presents the obvious characteristics of high voltage, and decreases slowly, which indicates the low resistivity feature of landfill leachate.

The apparent resistivity sections with depth along line is showed in Fig. 2 (b). The most prominent features are obvious layers, which performs the characteristic of "high - low – high" .These layers are irregular and their thickness varies. It is noticed that there is obviously high anomaly within depth 100--30 m and low lateral anomaly within depth -30 -100 m in corresponding zone of 3 -11 points. The trend of low anomaly gradually becomes shallow in the right zone of section. Beneath the low resistivity layer, at an apparent depth of about -100 m, the tendency of the resistivity increase with depth .In the section, on the right side, at apparent depth from -100--200 m, is a region with obvious high resistivity. It indicates the low resistivity feature of the landfill leachate, which are mostly ingathered in 120 m underground.

On the basis of features of high induction electromotive force and low resistivity, in the Multi-channel voltage profile in time domain and the apparent resistivity proposed cross-section diagram, saturation line is divided. Ranging gradually, the saturation line, is at the depth about 0 m. The depth in right part of the section becomes shallow, which is in keeping with higher ground in right zone. It indicates that saturation region is below the horizontal plane, in a safe level in tailings dam.

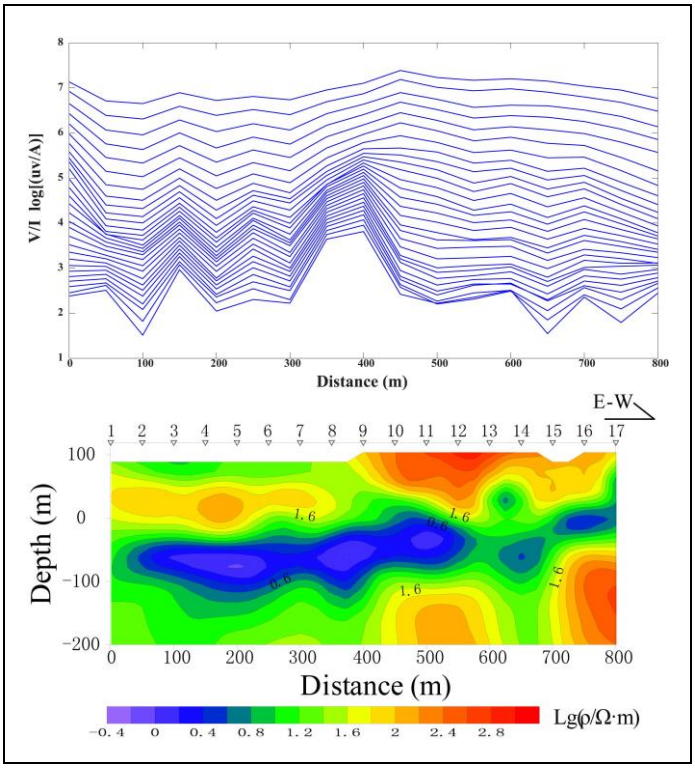

Fig. 3. The apparent resistivity vertical derivative anomaly map of line

In order to strength the vertical profile resistivity change, the vertical first derivative of the apparent resistivity cross-section is calculated, which is a reference for dividing layers. The apparent resistivity ranges with water content and lithological characters. Extreme value of vertical derivative, indicates the stratigraphic changes and water content changes.

In Fig. 3, the apparent resistivity vertical derivative anomaly map, values vary in a large range. Three boundaries are divided. The first boundary is minimum negative gradient, we interpreted the boundary as the top of saturation region, where the resistivity decreases because of water saturation. The second boundary is greater positive gradient, where the resistivity increases, representing the bottom of saturation region. The third boundary is Maximum positive gradient, which indicate the gradual stratigraphic variations The results also show that saturation region is almost below the horizontal plane. The size of layers are divided clearly.

The geological structure indicated by apparent resistivity of line is showed on Fig. 4. Across the center area of the tailings dam, the west side of line section is higher and stratigraphic distribution is relatively simple. Results show that four vertical layers are clearly divided. At the depth from about 100—-20 m, is a region with high resistivity. This layer represents tailing sand accumulation. The thickness of this layer is 110 m, which is in good agreement with local information. Below the accumulation, is the stratum of Quaternary strata. Due to the overlying backfilling percolation characteristics, this layer is sandstone, which is rich water-bearing. This region can be regarded as paleo-regolith. Beneath the paleo-regolith, at the depth of about -100 m, is the Cretaceous-Tertiary red glutenite. In the west side of section, the strata has a wide range of exposed surface layer. Bedrock is corresponding to Proterozoic metamorphic rocks of Lengjiahe. Shallow metamorphic slate forms the ancient basement. According to the field survey, it can be confirmed that saturation region is almost below the horizontal plane.

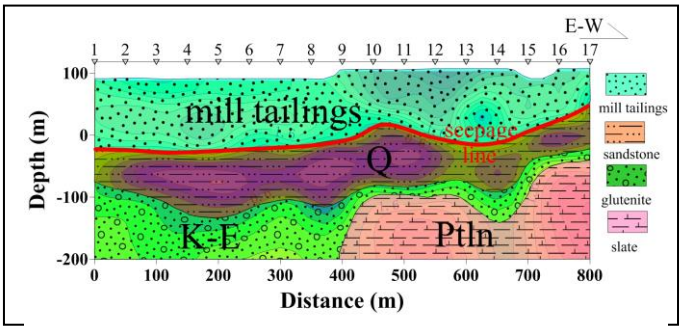

Fig. 4. The geological structure indicated by apparent resistivity of line

V. CONCLUSIONS

In this paper, the transient electromagnetic method is applied to the detection of dam saturation region. In the Multi-channel voltage profile in time domain and the apparent resistivity proposed cross-section diagram, a high anomaly characterized by “low resistance” in saturation region.

The vertical first derivative of the apparent resistivity cross-section is calculated to highlight the vertical profile resistivity change. In the apparent resistivity vertical derivative anomaly map, saturation line shows minimum negative gradient anomalies. The size of layers are clearly divided. The results shows that saturation region is almost below the horizontal plane, which provides reliable geological theory basis for Taolin tailings dam safety evaluation.

The results show that TEM is feasible and effective for the survey of underground water.

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REFERENCES

[1] Zheng Kui, 2011, Environmental conditions and comprehensive control of lead-zinc tailings in Linxiang county. Chinese Master's Theses Full-text Database, Hunan Agricultural University.

[2] Liu Guoxing, 2005, Electrical prospecting principle and method, Geological Press.

[3] Zhang Baoxiang, Liu Chunhua, 2004, Summarization on applications to groundwater exploration by using transient electromagnetic methods. PROGRESS IN GEOPHYSICS, 537-542.

[4] Han Ziqing, Luo Jiao, Liu Tao et al. 2015,The application of fixed source loop transient electromagnetic method in the coal mine rich water area survey, Progress in Geophysics, Vol.30 , No .4, 1705-1711.

[5] Wang Jian 2013, The application of Transient electromagnetic method to tunnel groundwater forecast in advance, Science & Technology Information.

[6] Niu Zhilian, 1992, Principle of electromagnetic method in time domain, Central South Press.

[7] Li Jinming, 2005, Geoelectric field and electrical prospecting, Geological Press.

[8] Chen Guisheng, 2001, The prospecting research of Transient electromagnetic method (TEM), Chinese Master's Theses Full-text Database, Central south University

[9] Bai Denghai, MAXWELLA MEJU et al. 2003, Numerical calculation of all-time apparent resistivity for the central loop transient electromagnetic methods. CHINESE JOURNAL OF GEOPHYSICS, Vol. 46, No .5 697-704.

[10] Li Jinming, Zhang Chunhe, Xiao chun,1999, Several experimental results of the relationship of the electrical conductivity and Excitation electrical of water pollution with pollution concentration change , CHINESE JOURNAL OF GEOPHYSICS, Vol.42 , No .3, 428-433

[11] Fan Liang, Qian Rongyi, 2011, Application of Transient Electromagnetic Method to Coal Mine Gobs. Chinese Journal of Engineering Geophysics, Vol.8 No.1 029-033.

[12] Yan Yueping, You Xianjun, Liu Lisheng et al. 2013, Linxiang polymetallic metallogenic zone gravity anomaly and the geological genesis, GEOPHYSICAL & GEOCHEMICAL EXPLORATION, Vol.37, No .1, 47-52.