Regularity of Transient Electromagnetic Methods for Detecting Hydrous Unfavorable Geological Body in Tunnel

Lubo Meng*, Tianbin Li*, Zheng Duan** and Zhu Jin***

Abstract

By using typical field cases, the transient electromagnetic response regularity of water charged underground solution cavities and fractures and response characters of low electric resistance bodies (which disturb transient electromagnetic field) have been generalized. The result indicated that apparent resistivity contour can play down obviously and form flexural or closed curve when hydrous cavity appear in front of detection workface; apparent resistivity contour can play down gradually and form small closed curve when hydrous cracks appear in front of detection workface; apparent resistivity contour chart will display fake abnormal phenomenon that is 'closed loop of low electric resistance', when lots of metal support and abundant surface water appear in the back of workface. It accentuates two points about transient electromagnetic method detecting, one is environment of detecting, and the other is interpretation method of combining geology with geophysical charts.

Keywords: *Transient Electromagnetic Methods; response characteristics; Unfavorable geological body; Ground water*

Introduction

Transient Electromagnetic Methods (TEM) which has sensitive response to low resistance body is a kind of advanced detection method based on electromagnetic induction. The method was firstly used in the field of surface detection, and some foreign experts and skilled workers in this field have researched on the spot working ways as well as interpretative methods and have indicated that the effect does work according to abundant practical application (Bangyuan, 1998; Spies, 1984; Xiu, 2002; Jingcun, 2007). In recent years, TEM are applied in advanced tunnel geological forecast by experts of the field with the combined help of interpretation map, table and the geological condition of the tunnel workface. Though the experts have improved the field working and the interpretation methods and have got some good fruits in resent years and Qingfeng (2007), Muming (2006), Junjie (2005) and Gang (2006) have applied the TEM into advanced tunnel water-exploration, the interpretation methods are not consummate and unified. And they have neither summarized the regularities nor got the wholesome interpretation regularity.

From the angle of forecasting unfavorable geological body, this article explores the response characteristics of TEM in unfavorable tunnel geological forecast on the basis of typical cases of exploring water-bearing unfavorable geological bodies of Tongluoshan and Mingyueshan tunnels by using TEM.

The basic principle and working method

The TEM is a kind of time domain method, using Laplace domain waveform electromagnetic pulse, with no grounding back to the front line. Vortex generates in the geologic body under the excitation of the primary field and its size depends on the conductive ability of the geological body, and if the conductive ability is strong then vortex

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is strong. After the primary field disappears, vortex can not disappear immediately, because there is a transition process (attenuation process), and the transition process produces a quadratic field to the attenuation of underground. The changes of the quadratic field will reflect the electrical conditions of underground medium by using receiver coil to receive the quadratic field. According to different delay time in the case of measuring induction e m f, we get the attenuation characteristics of quadratic field, thereby detecting various bad geological targets. The whole process is shown in Fig. 1.

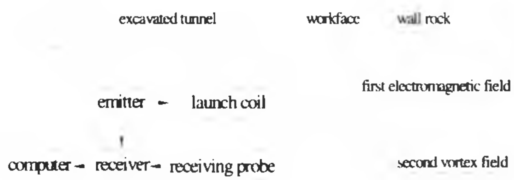

Fig. 1. Working principle of Transient Electromagnetic Methods

Doing TEM in tunnel belongs to the total space environment, which is different from half space environment on the ground, so the exploration method applicable in tunnel/ underground structure cannot be applied to ground method. At present in the TEM, the equivalent conductive plane method (also called " the longitudinal conductance explanation") is more appropriate (LI Xiu, 2006) because the longitudinal conductance explanation is sensitive to the thin low resistance conductive layer and is helpful to explain the unfavorable geological body, which is low resistant and water-filled.

The field tunnel detecting instrument is the IGGETEM-20 transient electromagnetic instrument (Fig. 2) by Chinese Geological Sciences of Geochemical Exploration Geophysics Institute (Qingfeng, 2005), and the launch and receiver coil were center line. The launch coil is 3m×3m×8 coil (Fig. 2), while the receiver coil is equipped with SB-250K (P) shielding probe. After measuring instrument, according to connect line layout, the launch coil should be moved at certain regular interval, which is generally 0.5 m (Fig. 3), and then the exploration can be done. After the results of detection are obtained, the IGGETEM - 20 Transient Electromagnetic Instrument data is anlysed with the help of a software (at TEM work station). The data analysis principle of that software is based on the equivalent conductive plane method.

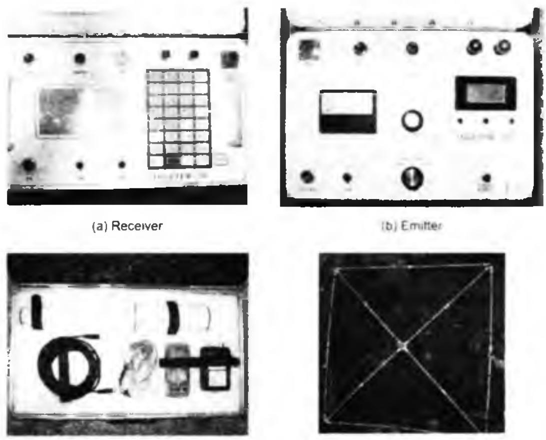

Fig. 2. The IGGETEM - 20 Transient Electromagnetic Instrument.

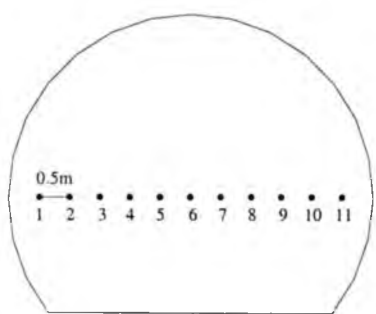

Fig. 3. Launch coil movement at regular interval of 0.5m at the working face.

Typical cases of field detection of unfavorable geological bodies

a. Detecting the water-filled body in solution cavity

The geological condition at YK34+750 workface of Tongluoshan tunnel: At this workface, thin to medium thick layers of mainly limestone and argillaceous limestone occurred. This section met the tunnel with a big angle, or met nearly horizontally. There were some yellow weak interlayers. The rock at the upper portion of the tunnel was cracked, and there were many rock blocks falling from the vault of the tunnel workface. The stability of the surrounding rocks was a little bad as some water was present in the crack between the layers, and the tunnel workface was wet on the whole.

Using IGGETEM-20 transient electromagnetic instrument to detect geological condition beyond YK34+750 workface, the apparent resistivity profile map ahead of the tunnel workface was obtained (Fig. 4). In the Fig. 4, the number in vertical coordinates is the depth or distance in m ahead of the tunnel workface, the number in horizontal coordinates is the number of the measuring points which are eight in total, for examples, "10" means the second measuring point, and "20" means the fourth. The distance between each point is 0.5m, and the measuring line is 3.5m long; The Fig. 4 shows apparent resistivity contours, which reveal the presence of very low apparent

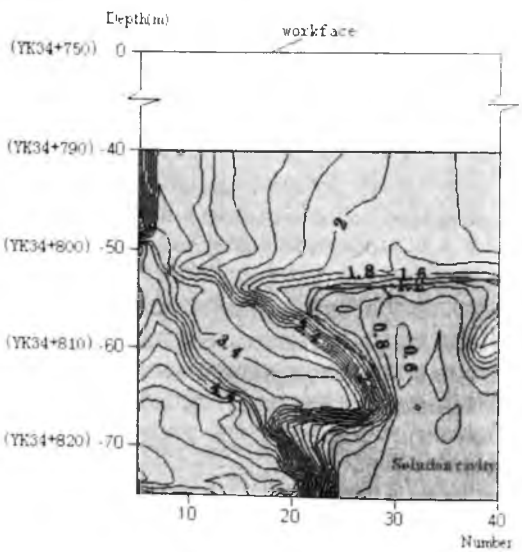

Fig. 4. Apparent resistivity contour map of Tongluoshan tunnel at YK34+750 workface

resistivity on the right side of the map from about 50m to 70m away (i.e. YK34+800 to YK34+825 section) from the tunnel face.

This tendency exists even in the unexplored depth. This phenomenon reveals that rock on the right side is more broken than the other side. Fissure water, even gushing water, may appear in the right portion of the above mentioned tunnel section.

Later, the excavation verified that the whole section was mainly occupied by limestone, jointed dolomites with fractures and fissures sandwiched between large smooth shale. The left side's lithology was in a better condition, while the right side was in broken shape and groundwater was dripping. When exploring the section of YK34 + 805, there is a small cave at the middle-lower partial right side as the forecast results.

b. Detecting gushing water in karst tunnel

Take the gushing water at YK6+471 of Mingyueshan Tunnel as an example. At 8 PM on December 14, 2007, the concrete on left side was broken by water that gushed into the tunnel with a discharge of 68 m^3 per minute together with some crushed fragments. The water was turbid, and some murky massive stones came into being at the same time, which were up to 2 to 3 meters size. Its color was mud yellow and had a lot of mud.

A detailed geological analysis of this region was conducted after this situation. Rocks of this area were of Jianglingjiang and Leikoupo Formation. While in the Sichuan Basin some common salt breccias interlining of the intrusions appeared there. The field geological survey found that dissolve breccias and gypsum did exist in the water within the karsts development. This can be inferred that existing tunnels have gypsum plaster, and the intense groundwater activity caused the dissolution of rock-salt forming the cavity. Besides Leikoupo formation along the tunnel axis, mudstone formed a water-resisting layer at about 40m above its bottom rock. From

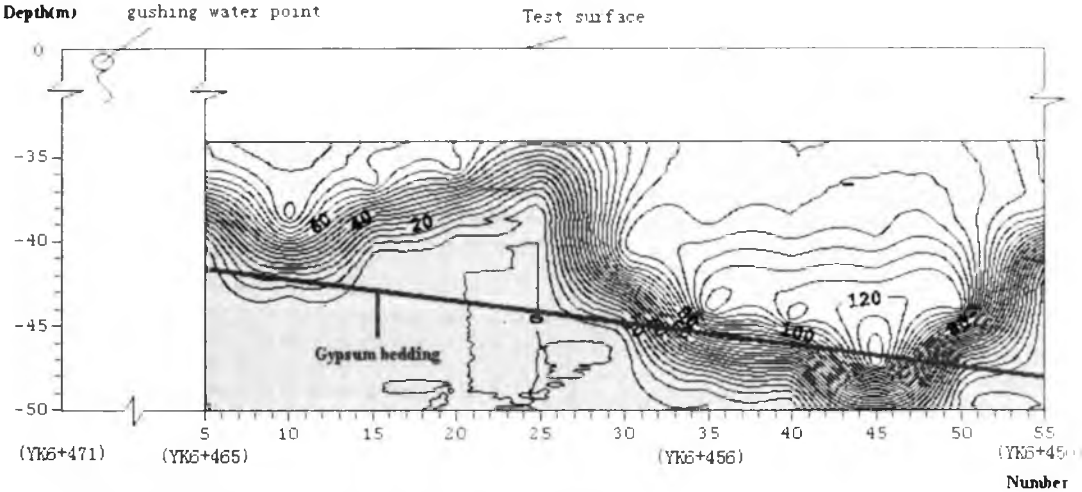

Fig. 5. Apparent resistivity contour map from YK6 + 450 to YK6 + 465

the above geological analysis, we can see that the salt layers do exist in the tunnel.

Based on geological survey analysis, geological condition was detected by TEM. Its starting point mileage is YK6 + 465, terminate YK6 + 450. The apparent resistivity is detected by the line as shown in Fig. 5, per point distance graph is about 1.5 m. Figure 5 shows that from YK6 + 456 to YK6 + 465 (number 5 to 35) and over the vault have a low impedance that is 39m above, which may exist or aqueous karst aquifer.

As per the above analysis of TEM, aquifer or aqueous karst cave may exist about 40m above the vault. It shows the possible existence of karst aquifer or a wider range spreads broadly and water content is distributed fully.

The results of TEM detection and geological analysis basically coincided with each other which all indicate that the rock-salt cavity with water that exist 40m above the tunnel axis was the cause of the sudden inflow of water.

c) *Detecting the fissure water-fiiled body*

Take the prediction for fissure water of Mingyueshan tunnel at K6+765 to YK6 + 820 as an example, the geological survey for K6+765 heading surface geology as below: lithology mainly consist of thin or medium black limestone and marlstone; strata was axis vertical, horizontal angle was relatively small, rock hole was nearly on the horizon level, Joints and fractures were comparably developed, the rock was generally broken, while interlayer adhesion was just medium. So overall, the heading surface was dry and the stability of the surrounding rock was medium.

Detecting K6+765 heading surface with TEM, of which obtained data would be processed and thus generates an apparent resistivity section (Fig. 6). Figure 6 show that 45 to 50m range is obviously of low resistivity, it can draw a conclusion that there exists water in fissure or dissolve gap.

The excavation then verifies that the hole major consists of limestone and clay, the fissures are well developed, and the stability of surrounding rock is poor. K6+805 to YK6 + 815 (i.e. sounding 32 to 34m), fracture water is relatively rich, presenting as spraying water. As the excavation continued, the groundwater decreased and changed to seepage or dripping, just consistent with the forecast results.

d) *The interference of rear low resistivity body to the detection*

Take the forecast of the ZK34+065 to ZK34+115 section of Tongluoshan tunnel as an example. The result of geological survey

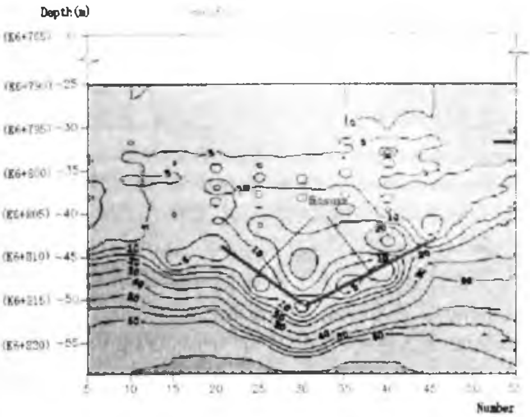

Fig. 6. Apparent resistivity contour map at K6+765 workface

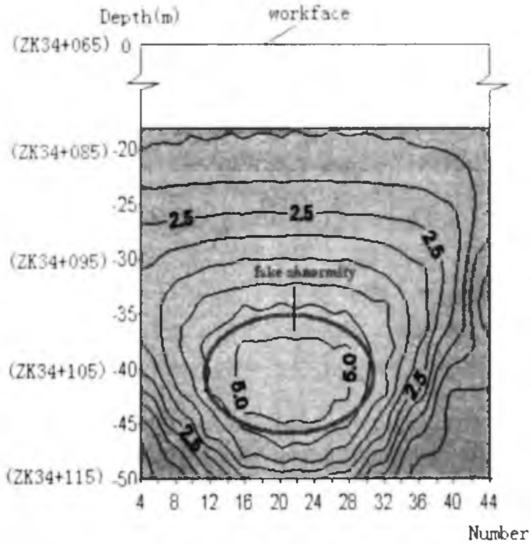

Fig. 7. Apparent resistivity contour map at ZK34+065 workface

of the ZK34+065 workface was that: the lithology was mainly thin-layer limestone and marl; joint fissure was developed to some extent and smooth, filled with yellow sand in the fracture, and the underground water was dripping; the stability of the surrounding rock was poor.

After detecting, the apparent resistivity profile map ahead of the tunnel workface was obtained (Fig. 7). Figure 7 shows that the contour of resistivity is close-loop type, and resistivity descends from center to periphery, that is, the impedance is high in the center of it, while low in the periphery. The result of the prediction is: period ZK34+100 to ZK34+110 (i.e., depth 35 to 45m ahead of the workface) has entered Jialingjiang formation, which is mainly limestone, argillaceous limestone and dolomite; there should not be too much water inflow, but there may be solution fissure filled with mud and fissure water.

But the actual situation of the excavation revealed that there was no dissolved gap filled with clay and little fissure water, which is different from the TEM prediction result. It was because strong influence of low resistance body behind the tunnel workface. Because the stability of the surrounding rocks behind ZK34+065 tunnel workface was very low, steel arch frames were used to advance the tunnel workface; furthermore, the tunnel workface was wet there was plenty of water-logging on the ground at workface. The overall effect was a “low resistivity closed ring” surrounding the tunnel workface, if we consider the steel arch frame and water-logging as a whole. The information showed in the apparent resistivity isogram was mixed up with the interference information behind the tunnel workface. Behind the tunnel workface there were low resistivity bodies, which suppressed most useful information. So the closure phenomenon of TEM apparent resistivity isolines actually was actually the effect of “steel arch frame and waterlogging on ground”.

To sum up, the disturbance due to the low resistivity body, close to the tunnel workface, needs to be avoided during the TEM investigation of the workface. If it is inevitable, a site record on the detecting environment must be done before the detection, and the influence of low resistivity body must be taken into consideration, especially the influence of the steal arch and the waterlogging on the ground. All of these can provide evidence for this detection.

Conclusions

Transient Electromagnetic Method is a good method to detect groundwater in tunnel, the distance of prediction is 30 to 50m. From above typical cases of groundwater detection analysis, it is possible to make some general remarks about Transient Electromagnetic Methods for detecting hydrous unfavorable geological bodies in tunnel.

(1) When a rich water cave exists in the front of tunnel workface, apparent resistivity contours will bend and even may close at the place where a water charged cavity is present, and it is significantly lower than other areas.

(2) When water-bearing fractures appear in the front of detecting points, apparent resistivity contours will close and form small rounds in the corresponding region of water-filled fractures/ fissures having low resistivity values.

(3) When the low resistivity objects such as metal or large ground seepage/ water exists in the back of detecting points, the phenomenon of closed resistivity ring may appear in such a maaner that the apparent resistivity contours would be close and decrease from centre to the periphery, that is to say, high resistivity zone is in the centre while low resistivity is towards periphery.

According to the above typical cases, it must be emphasized that two points needs to be considered essentially for getting suitable reliable result, one is detecting environments, which should avoid low resistivity interference, i.e. to keep away from metal brackets and keep the ground dry, the other is strengthening geological analysis by combining the resistivity map and geological data for good integrated interpretation.

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