Mapping the concealed structure using high-resolution EM - A case history of the investigation of B Tunnel route

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Summary

A successful case history of mapping the concealed structure using high-resolution EM in the investigation of B Tunnel route is presented in this paper. The high frequency electromagnetic system named STRATAGEM EH4, with the frequency ranging from 90 KHz to 1Hz, is used for the data acquisition. The orthogonal components of the electromagnetic field are measured, and the relevant electromagnetic attributes are extracted on the basis of the characteristics of the electromagnetic profiles. Hybrid sources, including the natural source and the full tensor controlled-source, are utilized to collect high quality field data. B Tunnel lies in the western part of Hubei province, the south of central China. The tunnel is only buried at the depth of less than 200 meters, but the geologic structure is very complex because of the regional geological action. During the first time of the B Tunnel route investigation, the investigators were deceived by the outcrop of the rock fall, considering that it is from the bed rocks and the roof of the tunnel fell when tunneling was in operation. High-resolution EM and seismic refraction were used in the second time investigation. The "real" bed rock and the geologic structure were mapped this time and a hidden fault was also detected. The tunneling result fits closely with what we have predicted.

Introduction

With the progress of the famous West-East Gas Pipeline Project, more and more pipelines have to go through mountains and the areas with complex geologic structures. The engineering geologic condition of the pipeline tunnel turns to be more and more complicated. As a result, the conventional route investigation methods, such as surface geologic examination and drilling, turn to be unfeasible in practice. Therefore, geophysical methods were mainly employed for the tunnel route investigation. The investigation of B Tunnel route is one of the successful examples.

B Tunnel lies in the western part of Changyang county, Hubei province, where exists the contact zone of Qinling Fold System and Yangzi Metaplatform, the first-level structural unit of China. The regional geology is dominated by the Great Xinhua Fault, which lies close to the work area. Xinhua fault is a north-east trending fault, which extends more than 360 kilometers. The fault is generated in Yeshanian, but it kept active in the Neoid tectonic movement. Two sites of hot springs have been found near the fault, and the great rockfall and an earthquake of magnitude 5 on Richter scale took place along the west side of the fault in late 1970's. This resulted in the complex geologic structure, especially in the shallow subsurface in the route of B Tunnel.

During the first time of investigation, the surface geologic examination has been carried out and a hole has been drilled, but the mass fall rock is considered as the bed rock by the investigators, and the roof of the tunnel fell when tunneling was going on. In order to map the geologic structure in a short time, the high-resolution EM and seismic refraction have been utilized in the entry part of the tunnel. The result indicated that the major geologic structure of the tunnel is a mass rock fall, below which the original bed rock is buried. The result of the investigation and the tunneling scheme were accepted by the tunnel builder. The tunneling result indicated what we predicted in our investigation was correct.

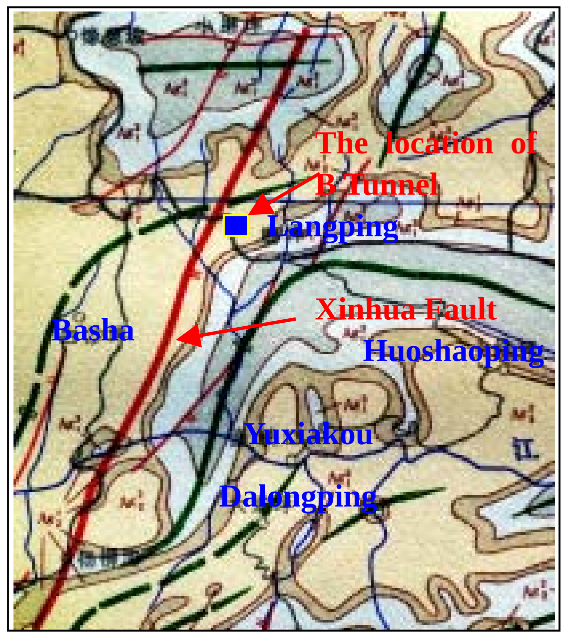

Figure 1. Geological location of B Tunnel

The frequencics used in our method is very high; the highest frequency has reached 79,400 Hz, and the frequency interval is very short, with 40 frequencies from 79,400 Hz to 12.6 Hz. This helps to improve the vertical resolution. At the same time, we used the minimal trace space and dipole space; the minimal space is only 8m, while the conventional space is often greater than 50m. This ensures the spatial resolution.

Data Acquisition

We carried out 17 high-resolution EM method sites in the work area. The survey line is shown in Figure 1(the blue line). The STRATAGEM EH4 real-time system was used for data acquisition. The system provides high-resolution electrical conductivity images of the subsurface at the depths between 10 meters and 500 meters, and the recorded orthogonal electric and magnetic fields data which are processed to provide tensor impedance measurements for interpreting complex 2-D structures. Two pairs of titanium electrodes, with a buffer between each electrode and the ANE (Analog Front End), and a separation of 8 to 16m, are used to measure electric fields; and highly sensitive magnetic coils are used to measure magnetic fields. Deep structures (more than 100 meters) are imaged using source fields provided by background magnetotellurics signals. A new portable low-power transmitter is used to supplement the background field signal, since it is very weak around 1000 Hz.

Data Analysis

The time series in the electric and magnetic fields were transformed into the frequency domain measurements by the Fourier transformation, which calculates and estimates of the magnetotelluric signal amplitude and phase, as a function of time and frequency. The results are corrected by the system parameters and responses so that the estimates are as accurate as possible, independent of the measurement system. The STRATAGEM EH4 program defines time windows and central frequencies in the way independent of the sampling interval or data acquisition start time. The 2*2 magnetotelluric impedance tensor **Z** relating the horizontal electric (*Ex,Ey*) to the horizontal magnetic (*Hx,Hy*) field was determined using the method provided by the GEOMETRICS. Ground resistivity can simply be calculated from the ratio of the amplitudes of the magnetic and electrics fields generated by the currents in the ground (telluric currents). Resistivity in Ohm-meters is $\rho = (0.2/f)*(E/H)^2$, where ρ is the apparent resistivity, E is the amplitude of the electric field, and H is the amplitude of the orthogonal magnetic field. Most sites have high quality data because no powerful high frequency noise exists in the area. Inversion has been done for the data set using Imagem-2D, which is a program from STRATAGEM EH4 system.

In order to analyze the effect of the topography, two models were constructed using 2-D finite element method. One is a pure topography model, and he other is geoelectricity model affected by the topography. The elevations of the topography used in the model were measured in the field. The depth of each layer and its filled resistivity in the geoelectricity model was abstracted from the inversion result. The result indicated that the effect of the topography in TM model is much weaker than that in TE model. The result of TE model data is shown in Figure 2. It is obvious that Figure 2(a) is different from Figure 2(b), but with the similar basic configuration. In this case, the influence of the topography mainly lies in “high frequencies”. It can be, in general, eliminated by the use of a filter. Although the result indicated that the elimination of the influence is necessary, the detail information especially the high frequency information is very useful to the detection of the microstructure in the high-resolution investigation. So we often use modeling to estimate the topography influence and choose a method to solve it. In the data analysis of B Tunnel investigation, EMAP was used for the topography influence elimination and static corrections.

Mapping of the concealed structure

The geologic structure mapping was based on the result of high-resolution EM survey, and in consideration of the seismic refraction result. The real structure of B tunnel is best indicated in Figure 3(a), expressed by the resistivity versus depth profile. We can extract the following information from the profile. Firstly, the high resistivity rock is deeply buried, unlike the conclusion from the first investigation. Besides, the high resistivity rock is discontinuous, and separated obviously by a low resistivity zone, which is very much like a fault (the fault also appeared in the velocity profile). According to the principle of “High resistivity relates to high velocity”, we compared the resistivity versus depth profile with the velocity profile (Figure 3(b)) to make sure the high-resolution EM result is acceptable.

Figure 4 is the geological profile of B Tunnel. The interpretation of the first time investigation Figure 4(a) only defines the first part of the tunnel route as Class **F**, and the other part Class **C**. The fact that the roof fell at Station 2048 denied the interpretation and led the second time investigation to the use of high-resolution EM. The result is mapped in Figure 4(b). There are four classes varying from Class **D** to Class **F** in the tunnel route. The relatively fresh rock (Class **C**) is hidden at the depth about 20 meters below the route. This is why the previous tunneling could not meet the bed rock. Besides, an undiscovered fault turned to be very clear after the second time investigation. This is very useful information for tunneling and it was verified by the later work. The tunnel met the fault at Station 2109, about 3 meters to the estimated location. Figure 4 (c) is the real tunneled rock classification result of B Tunnel. The major difference is between Station 2055 and Station 2064. The tunneled result is of Class **C**, while the exploration result is of Class **E**. Since there is no high resistivity or high velocity anomaly between Station 2055 and Station 2064, we consider the layer drilled as a mass block rock.

Conclusions

High-resolution EM is a very useful and practical geophysical method in the route investigation of pipelines. Our investigation based on this method proved that the concealed structure in B Tunnel is a rock fall. The relatively fresh rock interface and a hidden fault, which could endanger the late tunneling, had been clearly mapped. The integration of high-resolution EM and seismic methods will make the exploration result even more reliable.

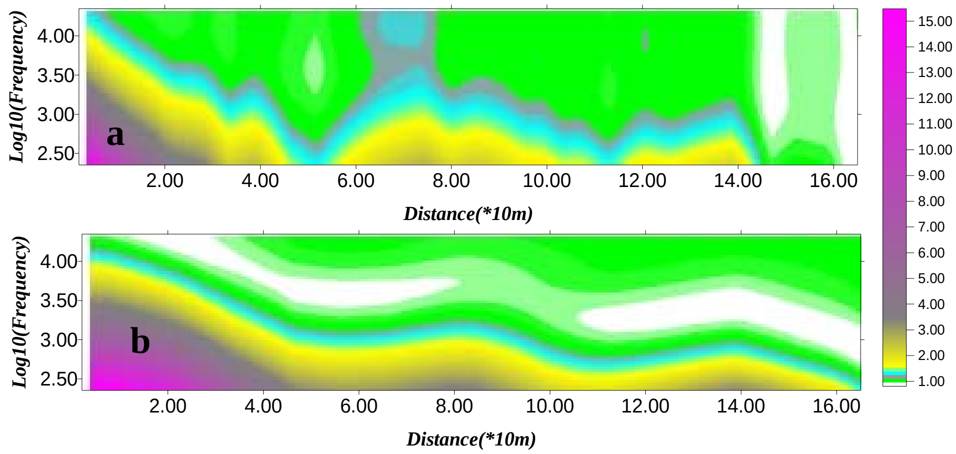

Figure 2 (a) The TE data of the geoelectricity model affected by the topography. Figure 2 (b) The TE data after the topography influence elimination (The data is calculated by the 2-D finite element method, and the apparent resistivity in this Figure is converted to the common logarithm).

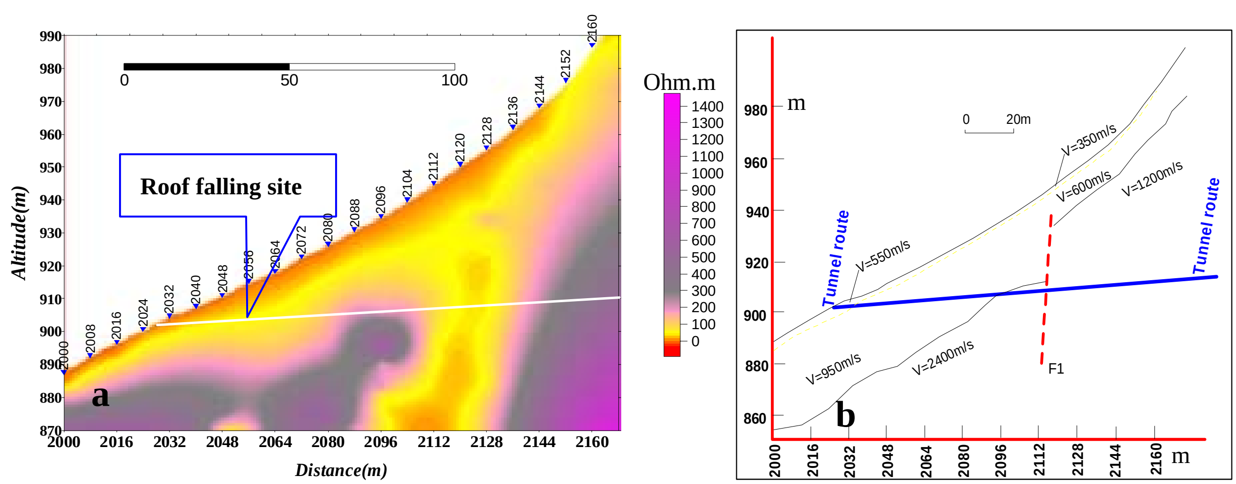

Figure 3: Resistivity and P-wave velocity profile of B tunnel (The resistivity versus depth profile (a) is from the result of high-resolution EM, and the P-wave velocity profile (b) is the result of seismic refractions)

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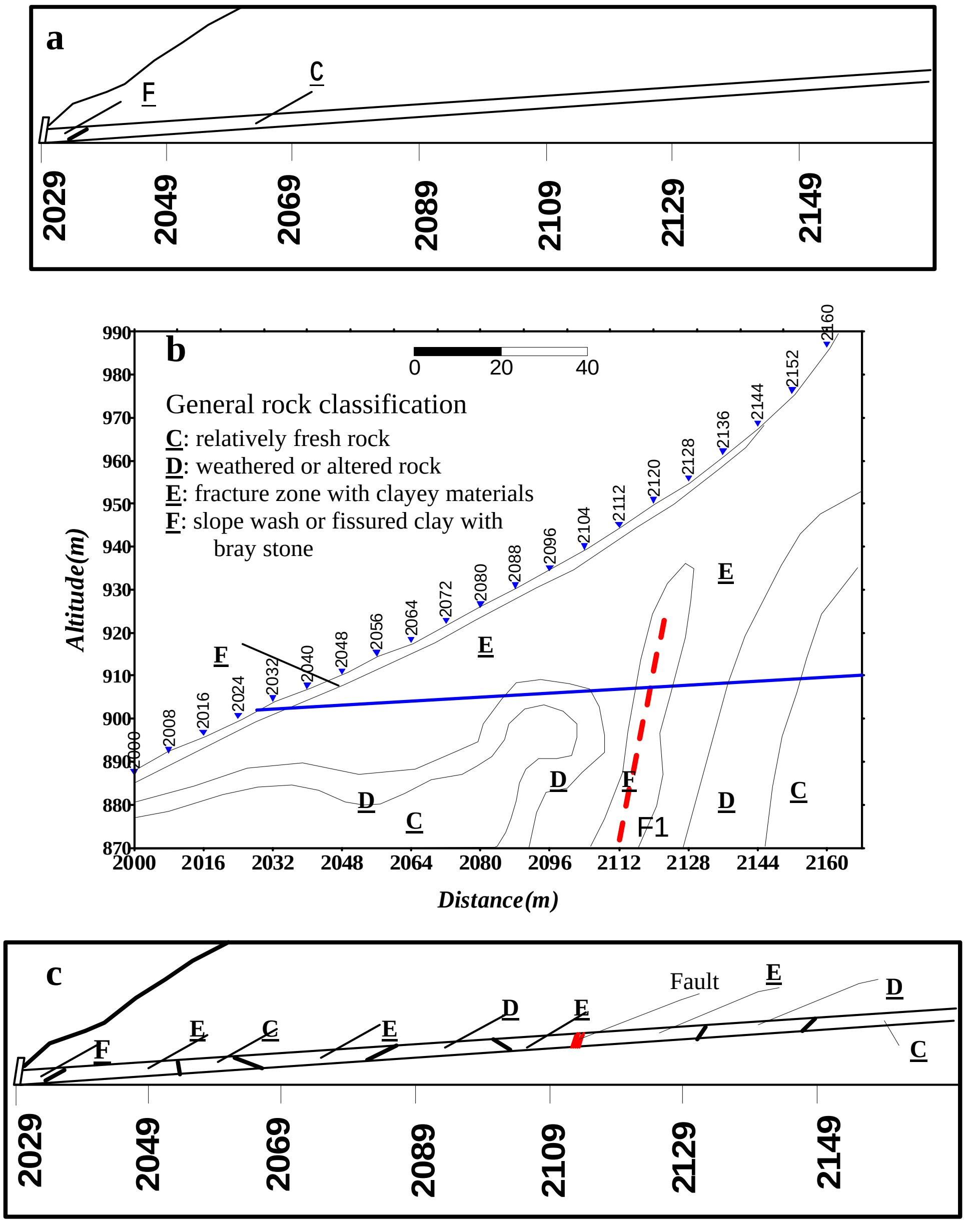

Figure 4: Geological interpretation of B Tunnel (Geological interpretation is mainly based on the rock classification, although the constituent of the bed rock often affects the measured resistivity). Figure 4(a) is the geological interpretation of the first time investigation, and Figure (b) the geological interpretation of high-resolution EM. Figure (c) is the tunneled result