Application of AMT in the Investigation of New Loushanguan Tunnel of Chongqing Guizhou Railway

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Abstract. New Loushanguan tunnel of Chongqing Guizhou railway is located in the karst and fault zone development section with strong water yield and complex engineering geological conditions. Through audio-frequency magnetotelluric(AMT) exploration, through data processing and two-dimensional inversion, the apparent resistivity profile of the tunnel is obtained. Combined with engineering geological data, the resistivity characteristics are analyzed, and the macroscopic lithology characteristics, karst development degree and fault fracture zone of the tunnel are explored the information of location and influence area provides geophysical basis for tunnel design and plays a guiding role in comprehensive geological investigation of deep tunnel.

1. Introduction

Xinloushanguan tunnel, with a total length of 4.58km, is located in the karst area, crossing the fault fracture zone, with complex engineering geological conditions and a maximum buried depth of more than 450m. It is an important control project of Chongqing Guizhou railway. The accuracy of geological exploration is of great significance to the later work; for the exploration of complex long and deep buried karst tunnels, it has always been an international problem, the main reason is that the terrain of mountain tunnels is complex and changeable, the exploration target body is buried deep, karst and mountain structure are developed irregularly, geological quality mapping and conventional drilling are difficult to accurately investigate the deep geological conditions, and conventional geophysical exploration means are also difficult. It is difficult to solve the problem of deep exploration. At the same time, complex topography will cause serious distortion of physical field distribution and form various forms of false anomalies. At the beginning of the 21st century, the railway design department of our country gradually applied the audio frequency magnetotelluric method to the investigation of deep buried tunnels, and achieved good results. This method has the characteristics of light instrument, suitable for the use in mountainous areas with bad terrain and climate conditions, fast acquisition speed, high working efficiency, little impact by the terrain, large detection depth, etc., from 10Hz to 100kHz. Its minimum detection depth is several meters to the maximum detection depth is 1000 meters, which is more suitable for tunnel investigation. In recent years, it has gradually become the mainstream method in railway and highway tunnel investigation. Through the method of audio frequency magnetotelluric sounding, good exploration results have been achieved in Loushanguan
tunnel survey, especially in the identification of deep karst development areas and fault fracture zones, which significantly improves the accuracy of comprehensive geological survey [1-3].

2. Method principle and key technology analysis

2.1. Fundamentals

Based on the theory of electromagnetic wave propagation and assuming that the medium ground is a non-magnetic body with uniform conductivity, the calculation formula of apparent resistivity ($\rho_s$) of underground medium can be obtained by simplifying the Maxwell equations

$$\rho_s = \frac{1}{5f} \frac{|E_s|^2}{|H_y|^2}$$

(1)

Where $f$ is the frequency, $E_s$ and $H_y$ can be observed on the ground, the apparent resistivity $\rho_s$ can be obtained, it is also called Kania resistivity formula.

By collecting natural electromagnetic field or manually established controllable electromagnetic field system and observing the change of $E_y$, $H_y$, $E_x$, $H_x$ in a certain distance far field area, the apparent resistivity contour map in the target area can be obtained, and the geological data such as target area mapping and drilling can be analyzed, then the range and depth of the abnormal body can be obtained, and the nature and shape of the target body can be judged, so as to survey the underground geology purpose of the situation [1-5].

2.2. Key technology analysis

2.2.1. Field collection.

In order to ensure the measurement accuracy, tensor measurement is adopted, i.e. four electrodes are shared for the work, each of which forms an electric dipole, and X and Y magnetic rods are used, which are arranged vertically with the corresponding electric dipole respectively. The magnetic rods are arranged as far away from the house, cables and trees as possible.

The electric and magnetic track preamplifiers shall be placed on the measuring point, i.e. the center of two electric dipoles. In order to protect the electric and magnetic track preamplifiers, they shall be grounded first and kept away from the magnetic rod, with a distance of at least 10m [3]. The specific layout is shown in Figure 1:

![Figure 1. Layout of field work collection](image)

2.2.2. Data processing. Data processing is the key link of audio magnetotelluric exploration, which is related to the accuracy of later interpretation results. The main steps are as follows:
• First, preprocess the time series data collected in the field, and then carry out FFT transformation in the field to obtain the virtual and real components and phase data of electric field and magnetic field.

• After preprocessing the data in one-dimensional inversion, establish a forward model to understand the distribution of the resistivity of the underground medium.

• The terrain correction, tensor impedance rotation and other fine processing are carried out, and the appropriate method is selected for two-dimensional inversion.

• Combined with the geological data and the established forward model, the constraint conditions are added to modify the inversion and gradually approach the real underground geological situation [1-6].

![Data processing chart](image)

**Figure 2. Data processing chart**

### 3. Application example

#### 3.1. Overview of the study area

Xinloushanguan tunnel is located in Tongzi County, Guizhou Province, with an altitude of 1000-1360 meters and a relative height difference of 360 meters. The terrain of the tunnel is relatively gentle. There are many bedrocks on the surface and vegetation is developed. The total length of the tunnel is 4585m, with a buried depth of 8-440m. It is a typical deep buried super long tunnel and one of the important control projects of Chongqing Guizhou railway. The bedrock of the tunnel is mostly exposed, and the stratum lithology of the tunnel body crossing is Ordovician middle Baota formation limestone, lower Meitan formation shale with limestone and sandstone, lower Tongzi Honghuayuan formation limestone and dolomite with shale.

The tunnel site is located in the West Wing of dingshancheng syncline, with many lithology. Fault FB-14 crosses from line D2K175+408, with strike of N32°E, dip of NW, dip angle of 85° and length of 780m as normal fault. The hanging wall and footwall are of the lower Ordovician (o1t-h) strata. The
occurrence of the hanging wall strata is N30°W/8°N, and that of the footwall strata is N30°W/3°N, which is a regional tensile fracture with certain water conductivity and great influence on the tunnel.

3.2. Geophysical characteristics
In order to prepare for geophysical interpretation of geophysical results, the background geophysical values of the work area are required. Therefore, in the early stage and during the process of geophysical exploration, the electrical parameters of geophysical exploration of representative rocks in the tunnel area are measured. According to the data analysis, the resistivity of the surface block gravelly soil is 200-800Ω.m, the bedrock is mainly Yanshan granite, and the resistivity of the complete rock mass is 200-800 Higher, ρs>20000Ω.m, there is a certain difference in resistivity between broken, weak or water bearing rock mass and complete rock mass; See Table 1 for test results.

| Formation lithology                                      | Apparent resistivity ρs(Ω.m) |
|---------------------------------------------------------|------------------------------|
| Extremely broken, weak, karst strongly developed or water rich rock mass | ≤200                         |
| Broken, weak, karst medium developed or water bearing rock mass | 200～1000                    |
| Relatively broken or karst medium weak rock mass         | 1000～2000                   |
| Relatively complete rock mass                           | ≥2000                        |
| Fault fracture zone                                      | ≤500                         |

It can be seen from table 1 that the resistivity of various rock layers is different, while the electrical parameters of various normal rock masses, faults and structural fracture zones are quite different, which provides the premise for geophysical field work and interpretation basis for data analysis.

3.3. Data processing and interpretation
In order to find out the macro geological situation of the whole tunnel, the geophysical survey line is arranged along the middle line of the road, and the distance between survey points is 20 m. The data are processed according to the above methods in this paper, and the 2D apparent resistivity profile (Figure 2) is obtained, and then the existing geological data in the work area are interpreted. The specific interpretation results are as follows (the focus of interpretation of the results is the geological situation near the design line of the tunnel, and the following generally refers to the relevant situation of the tunnel location (near the design line).

The electrical characteristics mainly show that the shallow resistivity distribution is disordered, the high and low resistance blocks and strips are interpenetrated with each other, and the distribution is uneven, indicating that the surrounding rock is generally broken, weak or karst medium developed. The overall resistivity of the tunnel body is medium low, and ρs is mainly less than 1000Ω.m, indicating that the surrounding rock is generally weathered and broken, and the karst is moderately developed.

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developed. In general, the resistivity of section DK146+4580~DK147+360 is disordered and unevenly distributed, with great gradient change. It is speculated that it is the area with strong karst development or the area with extremely broken and weak rock mass, among which, the resistivity is relatively low or concave distortion under the contour near the four tunnel bodies of section DK173+620 ~ +760,DK175+605 ~ +665,DK176+995 ~ DK177+040,DK178+030 ~ +240.It is the electrical reflection of the extremely broken and weak rock mass caused by the strong development of karst or the change of lithology.

The section DK175+358 ~ +398 of the tunnel body mileage shows the strip type low resistance reaction from the top to the bottom, which should be the electrical reaction of the fault fracture zone. It is speculated that the fault and the tunnel body intersect near the mileage, and the surrounding rock mass is broken, weak and may be rich in water. According to the geological data, the fault is the regional FB-14 normal fault.

![Figure 3. Tunnel inversion image](image)

The macroscopic results of geophysical exploration are consistent with geological inference. Geologists focus on the further mapping of the fault area inferred by geophysical exploration, which confirms the inference of geophysical exploration to the fault.

4. Conclusion

Xinloushanguan tunnel is a typical example of railway deep buried tunnel in complex mountainous area. Through geophysical exploration, the location and influence range of tunnel fault, the area where rock mass is broken or karst is strongly developed are found out. The sound frequency magnetotelluric detection technology has achieved good detection results under such complex conditions, which shows that the technology is suitable for tunnel exploration in mountainous areas, and is worthy of application and promotion. Because the acoustic magnetotelluric sounding method cannot provide the wave velocity of rock mass, and has multiple solutions in some parts, it is necessary to use a variety of exploration methods as much as possible in the work, and use a small number of boreholes to verify, so as to make the geological results closer to the actual situation [7-9].

Acknowledgments

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References

[1] ZHOU R F, WANG X B, QIN C, et al. 2016 Comprehensive utilization of NLCG and OCCAM in two-dimensional magnetotelluric inversion. Progress in Geophysics (in Chinese), vol 31, no 5, pp 2306-2312.

[2] Xia S B, Wang X B, Min G, et al. 2019 Crust and uppermost mantle electrical structure beneath Qilianshan Orogenic Belt and Alxa block in northeastern margin of the Tibetan Plateau. Chinese J. Geophys. (in Chinese), vol 62, no 3, pp 950-966.

[3] Zhao H, Wang L H, Li R. 2008 Application Study of Synthetic Electrical Prospecting for Deep-buried Long Tunnel Exploration. SITE INVESTIGATION SCIENCE AND TECHNOLOGY, vol 2, no 2, pp 61-64.
[4] Xu Z M, Xin H C, Tan X P, et al. 2018 An analysis of the experimental result of MT remote reference technique in strong electromagnetic interference region. Geophysical and Geochemical Exploration, vol 42, no 3, pp 560-568.

[5] Yu N, Li J, Wang X B. 2009 2D Magnetotelluric Inversion and Its Application in the Exploration of the Large Railway Tunnel. CHINESE JOURNAL OF ENGINEERING GEOPHYSICS, vol 6, no 5, pp 598-602.

[6] Li J, Deng H K, Zhang J D, et al. 2009 Application of geological routing about CSAMT exploration in Gaoligong Mountain tunnel of Dali-Ruili Railway. HYDROGEOLOGY AND ENGINEERING GEOLOGY. Vol 36, no 2, pp 72-76.

[7] Zhao H, Wang L H, Li R, et al. 2014 Application of Geophysical Prospecting Technology in Survey of Deeply-buried Long Tunnels On the plateau. Progress in Geophysics(in Chinese), vol 29, no 5, pp 2472-2478.

[8] WANG H, Ye G F, WEI W B, et al. 2013 High-precision acquisition technology of telluric field on magnetotellurics. Progress in Geophysics(in Chinese), vol 28, no 3, pp 1199-1207.

[9] J. van der Geer, J.A.J. Hanraads, R.A. Lupton, 2000 The art of writing a scientific article, J. Sci. Commun. 163 pp 51-59.