Application of high density electricity method in detection of concealed water conveyance tunnel

Bin Du, Lonjin Ge, Zheng Xu, Junjie Li
Zhejiang Design Institute of Water Conservancy and Hydroelectric Power, Hangzhou Zhejiang 310002, China
Email: 2439448450@qq.com.

Abstract. We used the high density electricity method to detect underground water conveyance tunnel in a project, then we compared the difference of apparent resistivity profiles between Schlumberger device and Winner device. Lastly, we analyzed the difference between the combined inversion method and the Levenberg-Marquardt method in Res2dinv software, and inferred the trend and depth of underground water tunnel through the results of electrical detection. Several conclusions are drawn as follows. Firstly, the resistivity anomaly of underground tubular object is more prominent in Schlumberger device than in Winner device. Secondly, the Levenberg-Marquardt inversion method which contained in Res2dinv software can easily conceal the horizontal resistivity variation characteristics of small-scale tubular anomalous body and the horizontal resolution of the original apparent resistivity profile is higher than that of the inversion result. Thirdly, the combined inversion method can improve the horizontal resolution of resistivity method for detecting tubular anomalous body with larger burial depth and smaller scale.

1. Introduction
There is a water conveyance tunnel with a diameter of 2.5m and a buried depth of 15m in an engineering investigation site, considering that the local tunnel line deviates from the tunnel design axis due to geological conditions during tunnel construction, if the surface drilling construction process penetrates through the tunnel lining, under the action of water head pressure, the water will gush out along the borehole, causing economic and property losses. Therefore, nondestructive physical detection technology is used to understand the plane of the concealed water conveyance tunnel Location is particularly necessary.

Shallow surface engineering geophysical exploration technology mainly includes ground penetrating radar method[1], seismic reflection wave method[2] and high-density electrical method[3]. Ground penetrating radar(GPR) is a high-precision and high-efficiency electromagnetic wave reflection technology. Its detection depth is related to the conductivity of underground medium and the main frequency of antenna. Because the survey area is located in the concave position, the overburden is thick, and the shallow soil has obvious absorption of electromagnetic wave. The effective detection depth of radar is usually less than 10m, which can not meet the requirements of exploration depth. The reflection wave method based on hammering excitation can obtain the reflection information of shallow geological body under small offset, but the surface of the survey area is mostly compacted gravel soil layer, so the coupling problem between geophone and gravel soil is difficult to solve. High density resistivity method is suitable for detecting underground objects with different electrical properties from surrounding media. It has strong anti-interference ability and large detection depth.
Moreover, high precision apparent resistivity data can be obtained by pouring salt water to reduce the grounding resistance near the electrode. This paper studies the application effect of high-density electrical method in the detection of concealed water conveyance tunnel under Wenner device and Schlumberger device, and use the inversion method of Occam algorithm[4] and Levenberg Marquardt method[5] in res2dinv software to process electrical data, the research results can provide a reference for the improvement of the detection accuracy of the electric method for the approximate circular objects with shallow cross-section.

2. The principle of high density electrical method and the layout of measuring line

High density resistivity method is an array imaging system which integrates the traditional electrode distribution methods such as Wenner device, dipole device and differential device into one. The system realizes the measurement of underground resistivity section through multi-channel electrode converter and supporting cables. In order to improve the efficiency of field data acquisition, two electrical measuring lines as shown in Figure 1 are arranged along the contour line in the concave position. The measuring line intersects with the designed tunnel axis at a large angle. The midpoint of the measuring line is controlled near the tunnel axis. The length of the line is 120m and the electrode distance is 2m. Schlumberger device and Wenner device are used receiving surface potential information. After removing the mutation point, the collected apparent resistivity data can be inversed by res2dinv software. Considering the small ratio of the diameter to the buried depth of the buried tunnel, in addition to the damped least square method, the combined inversion method of Levenberg Marquardt algorithm and Occam theory is also used for inversion imaging of electrical data.

[Figure 1. Measuring line layout of high density electricity method]

3. The analysis of resistivity profile results

Figure 2 shows the results of apparent resistivity profile of measuring line1-1’. As shown in Figure 2a, the apparent resistivity contour of Wenner device profile is gentle, the apparent resistivity horizontal difference is small, and the apparent resistivity tends to increase with depth in vertical direction, showing obvious layered characteristics, and the apparent resistivity changes in the range of 100Ω·M-800 Ω·M. The shape of the apparent resistivity profile of Schlumberger device is similar to that in Figure 2a, but the apparent resistivity contour line of Schlumberger device shows downward depression in the area with mileage of 74-78m and depth of about 14-25m as indicated in square frame in Figure 2b. The plane position corresponding to the abnormal center is only 2m away from the design axis of the tunnel, which is supposed to be the apparent resistivity anomaly generated by the concealed water conveyance tunnel.
Figure 2. Apparent resistivity profile of measuring line 1-1’

The results of apparent resistivity analysis in Figure 2 show that the Schlumberger device is more suitable for the detection of underground tubular abnormal bodies than the Wenner device, so the Schlumberger device is merely used to detect the measuring line 2-2’. Figure 3 is the apparent resistivity profile of measuring line 2-2’ based on Schlumberger device, as shown in Figure 3, within the depth of less than 20m, the apparent resistivity of the area with mileage less than 30m and mileage greater than 80m is less than 300 Ω·m, and the horizontal continuity of the apparent resistivity contour is poor. The location of the measuring line is near the waste drainage structure, construction waste such as surface hollow bricks can be seen everywhere, and the electrode grounding conditions are poor, so the data quality of superficial electrical method is poor. The apparent resistivity contour of the area with mileage of 43-47m and depth of 15-22m area is depressed downward marked square frame in Figure 3, which is similar to the abnormal characteristics marked in Figure 2b. The connecting line of the abnormal center is nearly parallel to the axis of the designed tunnel as shown in Figure. 1. According to the geophysical exploration results, we set up exploration holes ZK7-ZK10 at the location where the survey site deviates from the abnormal center line by more than 17m. The drilling revealed residual slope and bedrock, and no concrete was found, the results of electrical exploration avoid the construction risk of drilling in the survey area.
In many water conservancy projects, we found that when the terrain in the survey area is flat, the apparent resistivity profile can better reflect the electrical properties of small-scale geological bodies in the horizontal direction than the resistivity profile results after inversion. To illustrate this characteristic, we take the measuring line 1-1' as an example to inverse the apparent resistivity results. Except that the resistivity contour of the damped least square inversion result does not show the downward depression shape as shown in Figure 4a, the inversion results based on Schlumberger device and the processing results based on combination inversion shown in Figure 4b- Figure 4d all show the resistivity anomaly characteristics of buried water conveyance tunnel to some extent, but the depression range and depression degree of resistivity contour have some differences. The inversion results of Schlumberger device based on damped least square method only slightly depressed the resistivity contour in the area with mileage of 74-78m and depth of about 6-10m marked ellipse frame in Figure 4b, but the abnormal depth interval is not consistent with the design data. In the area with mileage of 76-82m and depth of more than 10m, the depression degree of resistivity contour is more obvious than the abnormal area shown in Figure 4b, but the contour curvature is smaller than the abnormal area marked by the apparent resistivity profile compare the marked area in Figure 2b, figure 4c and figure 4d. Therefore, the combined inversion method is more suitable for electrical data processing of underground tubular objects, but its inversion effect is not as good as the original apparent resistivity profile results. In addition, the resistivity of the damped least square inversion section is locally greater than 30000 \( \Omega \cdot \text{m} \), but the combined inversion resistivity value is mostly less than 7000 \( \Omega \cdot \text{m} \), and the combined inversion resistivity results are closer to the real rock resistivity value which mostly < 10000 \( \Omega \cdot \text{m} \).
4. Conclusions

Firstly, the resistivity profile based on Schlumberger device can better reflect the resistivity anomaly of buried tubular geological body than that based on Wenner device. Secondly, the damping least square inversion method can easily flatten the resistivity contour of the water conveyance tunnel, reduce the horizontal resolution, and its inversion effect is not as good as the original apparent resistivity results. Thirdly, the combination inversion method of Levenberg Marquardt algorithm and Occam algorithm can highlight the transverse resistivity variation characteristics of the geological body with approximate cross-section, and improve the accuracy of electrical data processing.

References

[1] LIU Zong-hui, LIU Mao-mao, ZHOU Dong. (2019) Recognition method of typical anomalies in karst tunnel construction based on ground penetrating radar attribute analysis[J]. Rock and Soil Mechanics, 40(8): 1–9.

[2] XU Jian-Yu. (2016) The application of seismic method to the investigation of active faults in urban shallow Quaternary sediment area[J]. Geophysical and Geochemical Exploration, 40(6): 1103–1107.

[3] LIU Qian, CHEN Jian-guo, ZHANG Yan-sun. (2018) Application of RES2DINV in the inversion of conventional electrical sounding data in Qingjiang basin, Jiangxi province[J]. Progress in Geophysics (in Chinese), 33(6): 2416–2427.

[4] Constable S C, Parker R L, Constable C G. (1987) Occam’s inversion: A practical algorithm for generating smooth models from EM sounding data[J]. Geophysics, 52(1): 289–300.

[5] JOSE P. (2007) The solution of nonlinear inverse problems and the Levenberg-Marquardt method[J]. Geophysics, 72(4): 1–16.