Research of Advanced Geological Prediction in Tunnel Excavation with Ultra-long Broken Zone

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Abstract. The advanced geological prediction is carried out by using ground penetrating radar, infrared water exploration and seismic reflection method (TSP) for the shallow fractured zone of Laoyingshan tunnel. The prediction accuracy is over 95%. It is suggested that the advanced prediction method can be used in the follow-up similar tunnel projects to improve the information level of tunnel construction and ensure the quality and safety of the project.

1. Background
During the construction of underground engineering, due to the unknown geological conditions in front of the construction face, geological hazards such as rock-collapse, water-mud inrush, coal and gas outburst, rock burst and shock bump often occur because of the poor geological bodies such as fault fracture zone, cast-development zone, high in-situ stress zone and high gas zone. Such case exists especially in areas with complex geological conditions such as alpine canyons and large burial depth. In order to reduce the occurrence of geological disasters, tunnel construction must have a full understanding of the geological conditions of surrounding rocks in front of the construction face. Rapid response and timely effective measure should be made to prevent the occurrence of disasters. It is not enough to rely on the engineering exploration because its accuracy cannot satisfy the requirements of the construction stage. Therefore, as a necessary procedure of tunnel construction, the advanced geological prediction is of great significance.

2. Properties of various geological prediction methods
Now the development and application of the advanced geological prediction technology for tunnels at home and abroad is not long, and it is still in a developing state. There are many immature places. At present, the commonly used technologies in engineering are geological survey method, geophysical method and advanced drilling method. The geological survey method is based on the existing exploration data of tunnels and the supplementary geological survey data of the surface. Through stratigraphic sequence correlation, correlation analysis of underground and surface of stratigraphic boundary and structural line, correlation analysis of fault elements and geometric parameters of tunnels, and precursor analysis of unfavorable geological bodies in adjacent tunnels, the excavation in
the front surface is inferred by using conventional geological theory, geological mapping and trend analysis. The commonly used methods are fault parameter method, surface geological body projection method, geological sketch prediction method, unfavorable geological precursor prediction method, etc.\cite{1-4}.

1) Seismic reflected wave method. TSP technology utilizes the propagation of weak seismic wave induced by artificial blasting in rock mass, and the reflected wave is received through a three-component sensor with high sensitivity. According to the propagation characteristics of shear wave and longitudinal wave in rock mass and based on the empirical wave velocity and physical and mechanical parameters model of rock stratum, the Young's modulus, Poisson's ratio of rock stratum and the potential lithologic interface intersecting with the tunnel axially can be obtained. In the same rock stratum, the longitudinal wave velocity keeps stable and abrupt change occurs at the interface. When the compactness, strength and stability of the rock stratum become better, the wave velocity increases. The corresponding Yang's modulus becomes larger, the Poisson's ratio decreases. The opposite values mean that the lithology becomes worse. The main equipment using this principle are TSP made in Switzerland and TGP series made in China, which are mainly used for long-distance tunnel prediction at present. The main problems of this method are: (1) the diversity of the processing results. The main manifestation is that when the same original data is processed, the final processing results differ greatly if the parameters such as frequency, data length, slope of P-wave and S-wave are different, which is one of the main reasons for the low prediction accuracy at present. (2) the original data is not qualified. At present, there are many non-geophysical prospecting and geological professionals in the advanced geological prediction team, who are not familiar with the in-situ geological conditions, and pay little attention to the work, such as non-standard boreholes, non-conformity of detonators and inadequate preparations on the spot, which make it difficult to obtain qualified original data.

2) Electromagnetic reflection method. The ground radar transmits short pulse electromagnetic wave through antenna, and receives the reflected wave reflected from the interface of rock strata. The spatial position of rock strata and unfavorable geological body can be judged by the spectral characteristics of reflected wave. In the process of electromagnetic wave propagation, the reflection occurs at the interface of different medium\cite{5-6}. The greater the difference of physical properties between the two sides of the interface is, the more obvious the reflection is. According to the radar waveform amplitude, frequency, energy-attenuation speed and phase-axis continuity, the target can be judged. In addition, the electromagnetic wave is sensitive to the water-rich area. The waveform features are phase reversal, low frequency, strong interface emission and rapid energy attenuation. The main equipment using this principle are geological radar series, which are mainly used for short-range tunnel prediction at present. The main problems of this method are: (1) there are too many interference factors in the detection results due to the influence of metal, pipeline and uneven rock surface; (2) different detectors have different understanding of the detection parameters based on the familiarity with the geological conditions in the field and the parameter setting, which results in inaccurate prediction results.

3) Infrared detection technique. The infrared water prospecting method is to monitor the infrared radiation field strength of rock mass. When there is water-layer in the rock mass, the infrared field strength of rock mass will be obviously distorted. By monitoring the distortion field strength, the prediction of water can be realized. Usually if the extreme difference of field strength is less than 10, the rock mass is normal; if the extreme difference is in the range of 10-20, the possibility of water-layer in the rock mass is small; if the extreme difference is greater than 20, the possibility of water-layer is large. The main instruments based on this principle are infrared detectors, which are widely used in coal mines. The main problems in tunnels are that there are too many in-situ interferences factors, such as large-scale working machinery, lighting fixtures, ventilation pipes, trolleys, which are superimposed with the radiation energy of poor geological bodies. In addition, it is impossible to quantitatively estimate the water pressure and volume.
3. Prediction contents and results
According to the actual situation of shallow-buried tunnel in this project, the main contents of this advanced geological prediction are: 1) the geological disasters such as water inrush, mud inrush and landslide in a certain range in front of tunnel face, 2) the integrity of surrounding rock in front of broken zone, 3) the prediction of water-rich and possible water inrush of surrounding rock by hydrogeological prediction. According to the type, location and water volume, the geologic body which affects the safety of construction personnel, construction progress and stability of engineering structure in a certain range in front of the palm is forecasted.

According to the survey data, it is predicted that the pile numbers of the left and right portions of Laoyingshan Tunnel passing through the Devonian fault fracture zone are ZK15+950-ZK16+260 and K15+900-K16+250 respectively. The shallowest cover is 25 m and the length of the shallow fractured zone is 660 M. In order to ensure the safe passage of the tunnel construction through the super-long shallow fractured zone, the advance prediction work is specially carried out.

The TSP prediction is made at K15+897 of the right side of the tunnel enter. The instrument uses TSP203plus with 24 points and 1.5m borehole spacing. The final effective number of boreholes is 20. The signal is processed by depth migration imaging as shown in Fig. 1-2.

Mudstone and breccia are the main strata exposed during the excavation of shallow section of the whole tunnel. The rock quality is relatively soft. The thin-bedded rock mass is relatively fragmented due to structural compression. The karst caves occur at the intersection of limestone and mudstone in the K15+900~K15+915 section at the left entrance, and the conditions for forming tunnels are poor. The surrounding rock exposed in the construction process is grade V, which is prone to collapse. Due to the great attention of construction, effective measures have been taken to support in time, and no large-scale collapse accidents have occurred during the whole excavation process. Within 120 m in front of the excavation surface, the P-wave velocity of surrounding rock is 1350-1560 m/s, the velocity ratio of P-wave to S wave is 1.45-1.65, the Poisson ratio is 0.35-0.45, the density is 1.55-1.75 g/cm 3, and the Young's modulus is 20-25 GPa.

![Figure 1 2D results of TSP prediction](image-url)
The method of point measurement with Laurel 100Mhz shielded antenna is adopted. The time window is 350ns and the bandpass filter is 25-250Mhz. The ground penetrating radar (GPR) buried in the face of the excavation surface receives the effect of rock burst loosening within 3 m. At the same time, the construction trolley also has some interference. Therefore, the radar wave reflects strongly and the coaxial axis is distorted with distorted image. The amplitude of local signal at K15+925~K15+929 is amplified and the frequency decreases. It is inferred that the water content of rock mass is larger. The reflection energy of electromagnetic wave at K15+932 is obviously increased and the coaxial continuity is good. It is judged that the developed cleavage fracture is well matched with the fracture mileage predicted by TSP, which further confirms the existence of the developed fracture. For the left and right arch walls of the tunnel, because the initial lining is supported by shotcrete and anchor with steel arch frame and the gap between the steel arch frame is 30cm, the interference on the electromagnetic wave is large and the effective signal is small, so the collected signal is difficult to judge the rock state after the initial lining.

In the process of tunnel excavation, dripping water or linear water outlets are exposed in many places, and the water volume at the water outlet varies with the variation of surface water and precipitation. The maximum dripping water volume is 1-3L/S per 10m tunnel section. Based on this, it is inferred that there is no large underground aquifer zone in the tunnel.

Generally speaking, the stratum limestone, mudstone and breccia that the tunnel passes through are exposed. The extremely thin, thin, medium to thick layers are randomly distributed, and the tunnel is in the shallow buried section. There is a certain scale of water-rich situation in these fractured zones. Fortunately, there is no large-scale water gushing phenomenon in the actual excavation. As far as the forecasting results are concerned, the forecasting results of each period are in good agreement with the actual excavation and the forecasting accuracy is over 95%.

4. Conclusions
Aiming at the shallow fractured zone of Laoyingshan tunnel, the advanced geological prediction is carried out by using ground penetrating radar, infrared water exploration and seismic reflection method (TSP). According to the prediction results, the conclusions are:
(1) Ground penetrating radar and seismic reflection data show that there is a karst cave of about 2.5m x 3.4m in the K15+900-K15+915 section without filling and water coming out from the cave. GPR data shows that the karst cave of K16+096-K16+094 section forms a small karst cave of about 1.0m*1.5m with no filling and water coming. The water volume of the cave is about 2L/S.

(2) Generally, a single prediction technology is easy to cause misjudgement. Synthetic advanced prediction technology can give specific information such as the spatial location and geometric shape of poor geological bodies, which effectively improves the accuracy of prediction and ensures the safety of construction. According to the engineering geological conditions, the corresponding prediction scheme should be formulated. After the specific scheme is formulated, the field test can be carried out and the scheme will be adjusted in time according to the test results, so as to ensure the selected technical means, parameter settings and scientific and reasonable detection methods.

(3) The surrounding rocks of the tunnel in this forecast section are mainly mudstone, breccia and breccia with dolomite. Mudstone has the characteristics of swelling, softening and shrinkage when exposed to water. The breccia after excavation is easy to form surface subsidence and vault subsidence when exposed to water, which is disadvantageous to the stability of the shallow tunnel section. During and after construction, surface monitoring and tunnel monitoring should be strengthened.

(4) The advanced prediction method is used to predict the shallow fractured zone and the prediction accuracy is over 95%. It is suggested that the advanced prediction method can be used in the follow-up similar tunnel projects to improve the information level of tunnel construction and ensure the quality and safety of the project.

References

[1] Wu, J., Mao, H., Ying, S., et al. (2003). Application of ground probing radar to short-term geological forecast for tunnel construction[J]. Rock and Soil Mechanics, 24(1):154-157.

[2] Deng, Y.D. (2004). Application of geologic forecast in wuqiaoling long tunnel[J]. Chinese Journal of Rock Mechanics and Engineering, 22(5):5140-5146.

[3] Li, S.C., Xue, Y.G., Zhang, Q.S., et al. (2008) Key technology study on comprehensive prediction and Early-warning of geological hazards during tunnel Construction in high-risk karst areas[J]. Chinese Journal of Rock Mechanics and Engineering, 29(7):1297-1307.

[4] Karp, J., Ravi, R. (2014) A 9/7-Approximation Algorithm for Graphic TSP in Cubic Bipartite Graphs[J]. Computer Science.

[5] Ma, K., Xu, J., Zhang, Z., et al. (2009) Research on advanced prediction and forecast of Xuefeng Mountain Highway tunnel[J]. Rock and Soil Mechanics, 30(5):1381-1386.

[6] Huangpu Ming, Kong Heng, Wang Mengshu, Yao Haibo, (2005) Effect of keeping core soil on stability of tunnel working face[J], Chinese Journal of Rock Mechanics & Engineering, 3:521-525.