Study on the Application of GPR in Tunnel Advanced Geological Forecast

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Abstract

On the background of a highway tunnel,ground penetrating radar(GPR) was used to undertake an advanced geological forecast research which is on the basis of geological analysis on the fault zone, water-rich area and the stability of surrounding rock within section ZK53+007-ZK53+037 and ZK52+724-ZK52+754. And several fault zones, water-rich areas and close-jointed areas were precisely predicted with the comparison of actual geological conditions. The results of the study illustrated the effectiveness and practicability of GPR in tunnel geological prediction at close range.Through this approach, new criterion and experience of GPR advanced geological forecast could be provided to other similar projects.

Keywords

Ground penetrating radar(GPR); Tunnel engineering; Advanced geological forecast; Tunnel face.

1. Introduction

With the expansion of infrastructure scale and further development of science and technology, tunnel works in both number and length showed a trend of gradually increasing, and thus higher requirements for tunnel construction safety is asked. In engineering, because of difficulty in engineering geological investigation, such as economic, technical, time, engineering density and other reasons, the proposed tunnel surrounding rock geological exploration is difficult to identify the different scale of geological structure and abnormity in detail[1], accidents caused by adverse geological are common. For instance: water and mud burst event of a tunnel on the Baikal-Amur artery in the former Soviet Union; In the construction of Chengdu-Kunming railway line in China, downtime occupied about one-third of project time due to geological problems; and Dujiangyan-Wenchuan express Dongjiashan tunnel in Sichuan province occurred fatal gas explosion accidents, which caused 44 people death, 11 people injured, and directly economic loss up to 20.35 million yuan [2]. How to use technical feasibly, safe and reliable advanced geological prediction technique to undertake further geological hazards forecasting,revise prior geological survey data and curb tunnel construction safety risks, which are the major technical problems urgently to be solved in tunnel construction[3].

Advanced geological forecast plays a extremely important role in predicting geological disasters and hazards and its extend in front of excavated face, reminding construction entity to take necessary measures to reduce the extent of disaster timely, ensuring the safe and smooth running of the project construction of the tunnel[2]. At present, commonly used advanced geological forecast methods are: the engineering geological investigation and inference method, advanced drilling method, seismic reflection method, ground penetrating radar and infrared detection method and so on[4-5]. Compared with other detection methods, geological radar has the advantages of light weight, fast, high resolution, strong anti-interference ability, non-invasive, etc. In tunnel construction geological prediction, especially in the short term prediction, GPR has been widely applied in actual projects [6].

2. Operational principle of GPR

GPR (Ground Penetrating Radar) is an engineering geophysical technology based on the difference of electrical parameters, such as conductivity and dielectric constant of the underground medium can detect the distribution of underground media by using high frequency electromagnetic pulse wave's reflection[7]. Its working process is as follows: transmitting antenna which is arranged on the ground transmits high-frequency electromagnetic pulse waves(frequency is of dozens to hundreds of megahertz and even to gigahertz) to the underground, if they encounter electrical difference (rock fracture zone, karst, fault fissure)geological interface when they are propagating in the ground, there is a part of the electromagnetic waves will follow the Snell reflection law be reflected, and the other part of the electromagnetic waves will occur transmission and continue to propagate downward; the portion of the reflected electromagnetic waves will be received by the receiving antenna host, and recorded by host, conduct rapid and continuous detection on each measuring points, and base on the reflection waveform and enhanced characteristics of wave groups, we can obtain GPR profile images after data processing; we can know the target site plane distribution via detecting extra lines, its working principle, as shown in Figure 1[8-10].

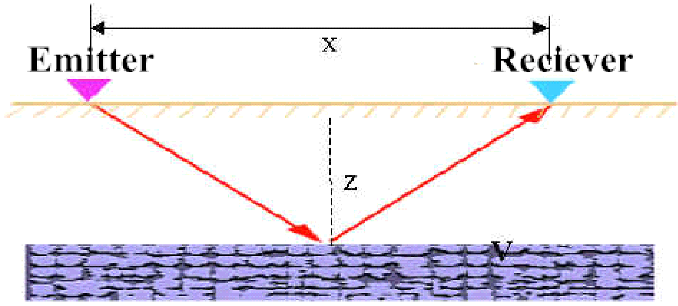


Figure 1: Simplified schematic of ground penetrating radar

3. Case analysis

Project overview. The main strata which is crossed and exposed by the site of the studied tunnel are: Cenozoic guar ternary Holocene loose sediments, The Middle Paleozoic Cambrian douposi formation (ϵ2d), lower Cretaceous Shilongdong formation (ϵ1sl) and lower Cretaceous Shipai formation (ϵ1s), the Sinian Dengying Formation of Upper Proterozoic (Zbd), the Shangliang formation, Dongfanggou formation (Pt2yt) and magmatic rock of Jinning age of the late Proterozoic (Pt2s). The tunnel layout and ZK51+400-ZK53+465 overall profile, as shown in Figure 2 and Figure 3. Geological conditions of the region tunnel passes through are very complex, therefore find out unfavorable geological conditions, such as the stratum groundwater, fractures, fault fracture zones and weak intercalated layer, in front of the tunnel tunnel face is of vital importance to the safety of the tunnel construction.

Detection is mainly carried out on ZK53+007-ZK53+037 and ZK52+724-ZK52+754, surrounding rock are mainly quartz diorite rock, and be of fractured blocky or massive structure, local surrounding rock may occur drop piece or meddile to large landslides when without supporting. There may be concealed extrusion broken belt, joint concentrated zones and other weak rock mass, groundwater mainly by intravenous drip like, the rain shaped and linear output, bad geology mainly concealed fault fracture zone, water outburst and rock burst, etc. There may be locally concealed extrusion broken zones, joint concentrated zones and other weak rock. The groundwater mainly put out in guttate, rain shaped and linear, unfavorable geology mainly include concealed fault fracture zone, water outburst and rock burst, etc. The on-site detection is conducted by using RAMAC/GPR ProEx type geology radar developed by Sweden MALA company, select RAMAC/GPR ProEx type host, main acquisition parameters of tunnel tunnel face test are: center frequency for shielded 100MHz antenna; the number of samples for each scan to collect 480; time window 750ns; superposition times 128. The on-site data is mainly collected by point measuring method.

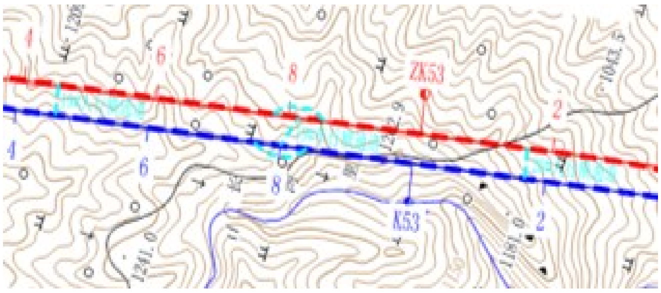


Figure 2: Overall floor plan of the tunnel

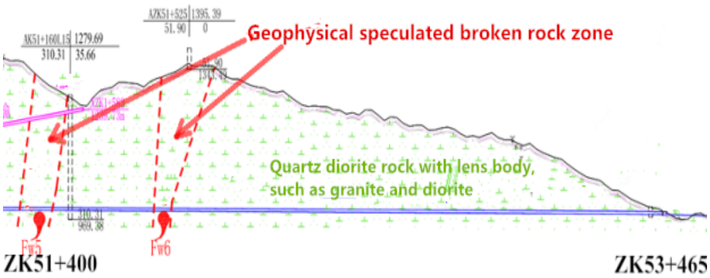


Figure 3: ZK51+400-ZK53+465 overall profile

GPR detection on ZK53+007-ZK53+037

Geological conditions at ZK53+037 tunnel face

Through the field observation of the ZK53+037 tunnel face surrounding rock (Figure 4), geological conditions at this position are as follows:

(1)Formation lithology: Surrounding rock around ZK53+037 tunnel face is mainly Jinningian slightly weathered quartz-diorite, belonging to extremely hard rock, blocky structure and appeared micro deterioration (tabular) under the tectonic extrusion effect of rock.

(2)Joint structure: The rock mass is intrusive rock (plutonic rock), the joint is not so developed, surrounding rock is relatively stable. There is a set of structural joints, occurrence and line density, as shown in Figure 5.

Figure 4: Tunnel face at ZK53+037

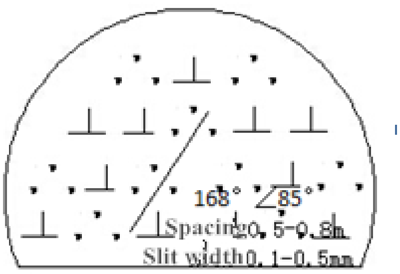


Figure 5: Tunnel face sketch at ZK53+037

(3)Hydrological geology: Surrounding rock around ZK53+037 tunnel face have a small amount of seepage, belonging to the bedrock fissure water, no sand and have small influence on construction.

(4)Karst: no karst development has been found.

GPR detection

According to the present situation of construction of tunnel ZK53+037 working face, the measuring line is set at the bottom of the face, length is 12 meters and 1.5 meters away from the bottom, line layout diagram, as shown in Figure 6.

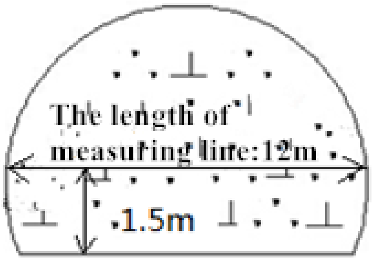


Figure 6: GPR measuring line layout diagram

GPR forecast range is ZK53+037-ZK53+007 segment, 30 meters long. GPR detection result image is shown in Figure 7.

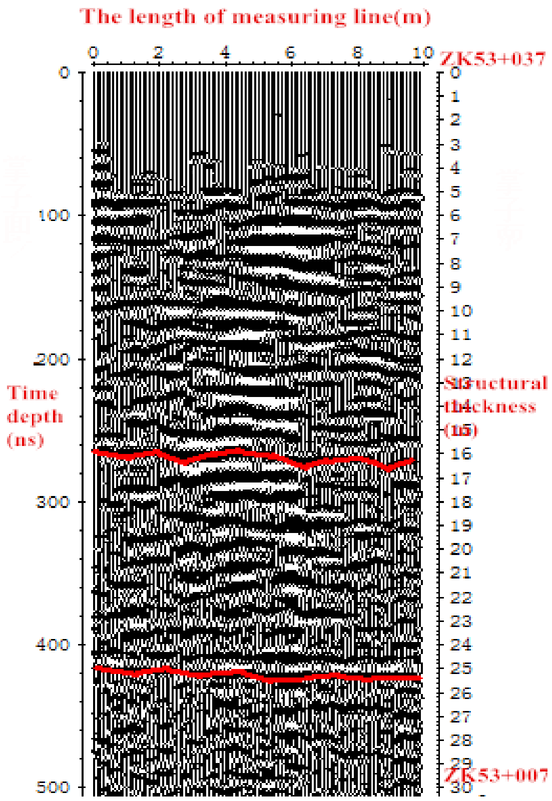


Figure 7: Detection result of GPR on ZK53+037-ZK53+007

GPR detection on ZK52+724-ZK52+754

Geological conditions at ZK52+754 tunnel face

Through the field observation of the ZK52+754 tunnel face surrounding rock (Figure8), geological conditions at this position are as follows:

(1)Formation lithology: Surrounding rock around ZK52+754 tunnel face is mainly Jinningian slightly weathered quartz-diorite, belonging to extremely hard rock, blocky structure and appeared micro deterioration (tabular) under the tectonic extrusion effect of rock .

(2)Joint structure: The rock mass is intrusive rock (plutionic rock), the joint is not so developed, surrounding rock is relatively stable. There are two sets of structural joints, occurrence and line density is shown in Figure 9.

Figure 8: Tunnel face at ZK52+754

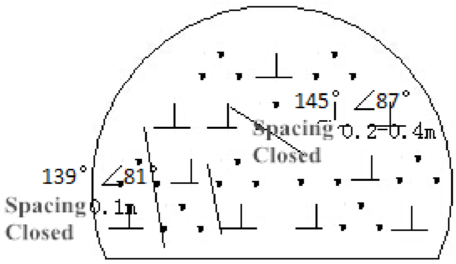


Figure 9: Tunnel face sketch at ZK52+754

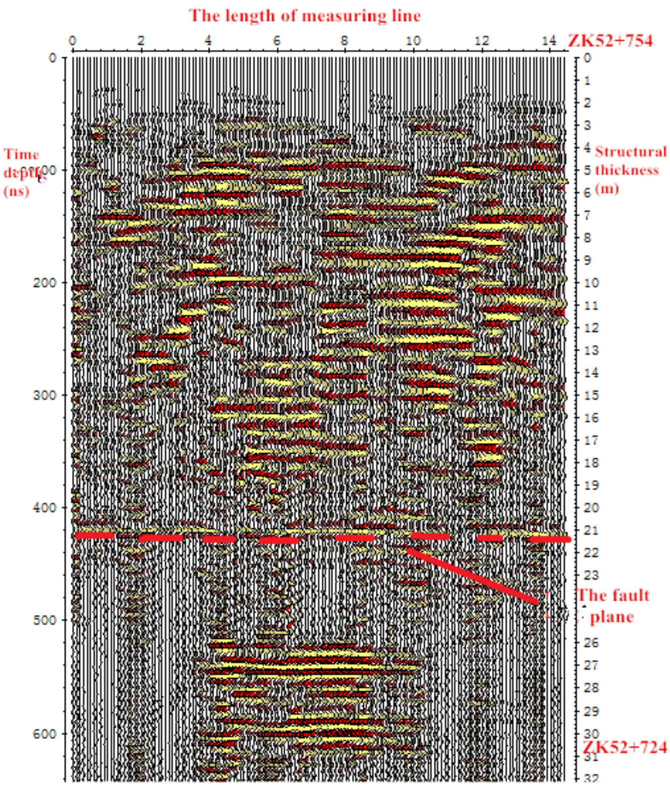


Figure 10: Detection result of GPR on ZK52+754-ZK52+724

(3)Hydrological geology: Surrounding rock around ZK52+754 tunnel face is relatively dry, and no seepage have been found.

(4)Karst: no karst development has been found.

GPR detection

The measuring line layout is the same as ZK53+037 tunnel face.

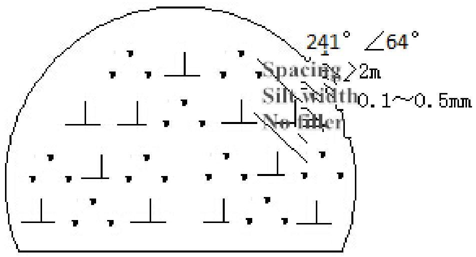
GPR forecast range is ZK52+754-ZK52+724 segment, 30 meters long. GPR detection result image is shown in Figure 10.

The comparison of GPR prediction and actual geological condition

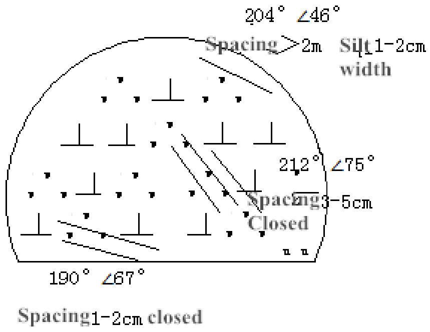
GPR spectrum performance of abnormal area of GPR detection data and its prediction results and the actual condition of surrounding rock after excavation is shown in Table.1.

Table 1: Comparison of GPR prediction results and actual geological conditions

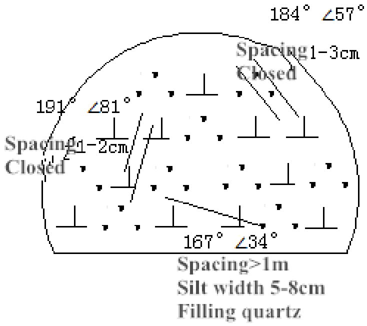
Mileage	Spectrum performance of GPR	Prediction results	Actual geological conditions
ZK53+037-ZK53+032	Event of signal is not continuous, a small amount of intermittent and leaps, low frequency, low amplitude and oscillation is not obvious.	Surrounding rock of this section: joints are relatively developed, rock mass is relatively broken,integrity is relatively poor, and have fissure water, characteristics of the surrounding rock is similar to the tunnel face.	Surrounding rock of this section: local joints is concentrated and broken, integrity is relatively poor, tunnel face is understable, there are dropwise bedrock fissure water outflow on the right side of the shoulders. ZK53+033 tunnel tunnel face geological sketch is shown in Figure 11(a).
ZK53+032-ZK53+007	Band combination of return of electromagnetic waves are relatively abundant, event of signal is not relatively continuous, exist some intermittent and leaps, intermediate frequency, high amplitude and oscillation is obvious. In front of the excavated face, 260ns and 420ns, the electromagnetic wave signals are continuous and there is an obvious line.	Surrounding rock of this section: joints are close and developed, rock mass is broken, integrity is relatively poor, and have fissure water, characteristics of the surrounding rock is abundant.Two developed fault planes in the fracture zone are predicted at ZK53+021 and ZK53+012.	Surrounding rock of this section: integrity is relatively poor, tunnel face is understable, water emitted at crown is shown in Figure 12. ZK53+021 and ZK53+012 tunnel tunnel faces geological sketches is shown in Figure 11(b) and Figure 11(c).
ZK52+754-ZK52+749.5	Electromagnetic wave returns are poor, event of signal is not continuous, exist a small amount of intermittent and leaps, low frequency, low amplitude and oscillation is not obvious.	Surrounding rock of this section: joints are developed,rock mass is relatively broken, integrity is relatively poor and there is no fissure water have been found, characteristics of the surrounding rock is similar to the tunnel face.	Surrounding rock of this section: integrity is relatively poor, tunnel face is understable, no seepage. ZK52+750 tunnel tunnel face geological sketch is shown in Figure 11(d).
ZK52+749.5-ZK52+733	Band combination of return of electromagnetic waves are relatively abundant, event of signal is relatively not continuous, exist some intermittent, intermediate frequency, high amplitude and oscillation is obvious.	Surrounding rock of this section: blocky structure and appeared micro deterioration(tabular) under the tectonic extrusion effect of rock, so that a plurality of reflection interface caused by multiple extensible joints are approximately parallel, rock block shape appears to be plate-like and irregular, structural joints is intensively developed, rock is broken and integrity is poor.	Surrounding rock of this section: rock is broken, tunnel face is understable,no seepage. ZK52+740 tunnel tunnel face geological sketch is shown in Figure 11(e).
ZK52+733-ZK52+724	Electromagnetic wave returns are poor in general,event of signal is not continuous, exist some intermittent, low frequency and amplitude oscillation is not obvious, but there exist intermediate frequency signal at local. Electromagnetic wave returns are continuous at 420ns, present obvious linear shaped reflection band.	Surrounding rock of this section: joints are closely developed and broken at local, integrity is poor, there may have locally abundant fissure water. A fault plane (compresso-shear) in fracture zone is predicted at ZK52+733.	Surrounding rock of this section: integrity is relatively poor, tunnel face is understable, Linear water outflow at crown, no sand. ZK52+733 tunnel tunnel face geological sketch is shown in Figure 11(f).



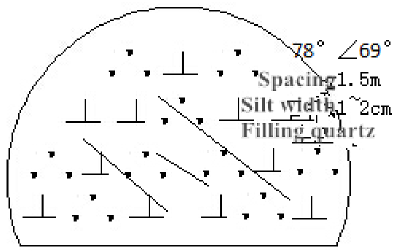
(a) Tunnel face sketch at ZK53+033



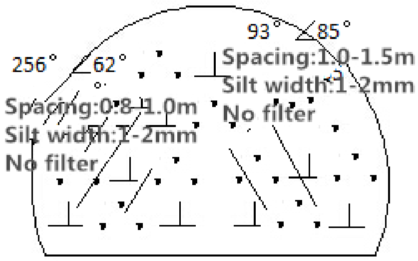
(b) Tunnel face sketch at ZK53+021



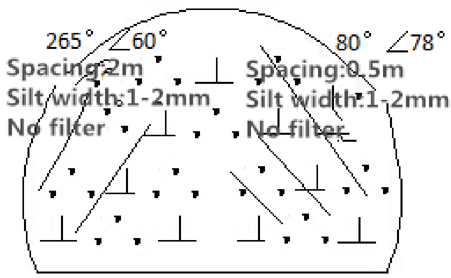
(c) Tunnel face sketch at ZK53+012



(d) Tunnel face sketch at ZK52+750



(e) Tunnel face sketch at ZK52+740



(f) Tunnel face sketch at ZK52+733

Figure 11: Tunnel face sketch on ZK53+007-ZK53+037 and ZK52+754-ZK52+724

Figure 12: Water outburst at ZK53+021 crown left side

4. Conclusions

(1)Apply GPR to accurately forecast several unfavorable geologic body within a certain range of tunnel face, such as groundwater, fracture zone, fault and so on, which is of extremely vital significance to the tunnel construction, provide the construction unit reliable supporting basis and ensured construction safety.

(2)Short term advanced geological forecast of The key predict sections is conducted according to the mode that geological sketch qualitative description combines with GPR geophysical detection, and received very good effect in the practical application, greatly reduced the impact of adverse geological conditions on the safety construction of tunnel, successfully achieved the purpose of advanced geological prediction.

(3)Combining with the tunnel tunnel face geological sketches, through engineering geology qualitative, we can make a macroscopic prediction of the development of unfavorable geologic conditions along the tunnel line side, to be a radar image interpretation criterion. Through this approach, workload of the forecast can be greatly reduced, impact on the construction progress can be diminished, and advance geological forecast accuracy is also improved. That is a reliable forecast model for this tunnel and other similar engineering geological prediction.

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