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Research on Tunnel Engineering Geological Exploration System Based on Tunnel Seismic Predication and Ground-penetrating Radar

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In this paper, the author researches on the tunnel engineering geological exploration system based on ground-penetrating radar. This paper complete exploration system design and production. System consists of adjustable signal source, voltage acquisition device, channel switching device, communication devices and current monitoring device. Exploration device is applied to experimental. A variety of geological conditions were simulated experiments. Complete measurement data acquisition. Measurement results are stored in the PC. Results of experimental verify the simulation. Through simulation and experiment can be found anomalies of resistivity changes will make changes in the electric field distribution. When resistivity of anomaly is certain, Changing in position and shape of the measured voltage value will be affect. The geological prediction theory of ground-penetrating radar is better understood. Simulation results help to research the real-time detection of abnormal response characteristics and detection results of the interpretation.

1. Introduction

Tunnel belongs to the underground construction engineering, during the construction, we often meet multifarious geological hazard, such as dashing out the mud, water, gas and the rock outbursts. With the increasing of tunnel engineering in our country, they become into deeper, bigger, longer, the engineering geological and hydrological geology problem being more complex, the theory study and practice on the ahead detecting and predicting are becoming more significant. Ahead detecting is basic on the difference of the medium’s geophysical property. It is the application of the geophysical exploring methods in the tunnel, underground well, stops. Through the observing distributions and the mutative rules of underground physical field, we can find the geological abnormality and make certain their scale and state. Base on principal and prediction law of TSP (Tunnel Seismic Predication) and GPR (Ground Penetrating Radar), combining their application in the ahead prediction, Xiao’s (Xiao et al., 2012) paper have elucidate the main types, reasons, geological features and the physical mechanical properties of the tunnel geological hazard. Base on sandwich model and the principal of seismic reflection method, author deduces the equation of the time-distance curve, discusses features. The composed record of multilayer models is simulated using Ricker subsidiary wave and minimal phase subsidiary wave. The resolving power of seismic wave on folium was discussed from tune thickness. The relation was taken a pated between the reflectance and an incidence angle and stratum "space angle". Yan’s (Yan et al., 2013) paper also presents the characteristics, data processing procedures of TSP203 system, and discusses the main influencing factors. The author has design an "equator combined demodulation observation system". (Yi, 2016)An accurate first velocity has been afforded for after revision. On the other hand, basic on the principal of the GPR, the author simulates some models of dual layers horizontal medium and combined cylinder using Finite-Difference Time-Domain Method and exceed absorb bound condition. The rationality and validity of this kind of simulation are proved by Qian-Gui railroad’ radar detecting. The general principal of radar images of different rock strata and karst are summarized in Yuan’s paper (Yuan et al., 2014). The main influencing factors and key technology of GPR were discussed in his paper. Theory

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and practice have make know, that TSP method mainly reflects the rock's mechanical property so belongs to the long distance geological forecast, and its detecting effects is better to the layered media, but detecting effect is unperfected on mini type karst, its interpret to the long distance is not enough accurate. GPR mostly reflects the electric property and dielectric properties of the media; its resolving power is upper than before. It has a higher resolution so the capacity of discernment of the karst, interlining, and fault zone is rather high. But its debating distance is not enough long. TSP should be adopted on long distance ahead forecast. GPR should be adopt on witch there is dubitable by TSP or there is a karst. Combined with the geology structural properties, Hong's paper (Hong et al., 2014) have to comprehensively analyse and explain the observing data to test, verify, supplement each other, to advance the reliability of the ahead forecast.(Kaushal, 2016)

2. The Model of Tunnel Engineering Geological Exploration System

With the rapid national economic development in west China, infrastructural construction, especially railroads in mountain areas are greatly improved in recent years. In the process of railroad construction in these areas, some deep and long tunnels are often needed. So tunnel construction, safe and on schedule, is extremely important for the infrastructural construction project in west china. On account of complex geological structures and limited budget, local unfavourable geological bodies cannot displayed absolutely. Unfavourable geological structures such as faults, fault fracture zones and karst caves, often increase the risk of geological disasters like collapse and flood in part districts, and result in serious damages, delays, and thus great economic losses. By advanced geological forecasts, unfavourable geological conditions can be detected, and thus countermeasures can be selected in advance. Accordingly, to meet knowledge of geological conditions in front of working face, advanced geological forecast, accurate and in time, is important. With application of advanced detecting methods in home and abroad, to forecast unfavourable geological structures in front of working face, accurately and in time, many sensors are currently investigated for this demand, for example ground-penetrating radar(GPR), tunnel GPR is a quick, continuous and non-destructive geophysical prospecting method. GPR data, based on accuracy of exploration and interpretation, excellence of resolution and capacity of mapping 3-D, is suitable for detecting karst caves, underground rivers, water-rich zones and cellars. (Zhou, 2014)

System consists of adjustable signal source, voltage acquisition device, channel switching device, communication devices and current monitoring device. Exploration device is applied to experimental. There was abundant fissure water in the surrounding rock of the landslide section. The distribution of groundwater was controlled by the geological structure. Various tectonic structural planes constitute the main water-bearing structure. In the role of the current tectonic stress field, most of the compressive structural plane in the echelon fracture zone occurred tensile and formed the space of the groundwater-flow. GPR mostly reflects the electric property and dielectric properties of the media; its resolving power is upper than before. It has a higher resolution so the capacity of discernment of the karst, interlining, and fault zone is rather high. But its debating distance is not enough long. TSP should be adopted on long distance ahead forecast. GPR should be adopt on witch there is dubitable by TSP or there is a karst. Through simulation and experiment can be found anomalies of resistivity changes will make changes in the electric field distribution. When resistivity of anomaly is certain, Changing in position and shape of the measured voltage value will be affect.

Long deep tunnels are ones which buried deeply, having long distance and complex geological structure. For this reason, long deep tunnel investigation has been the difficulties in the field of engineering geological investigation, which is related to the key technical problems of the tunnel route selection and construction, if the pre-rock exploration in the study of the geological structure is detailed, then the latter part of the design and construction could adapt more targeted technical measures, which can reduce the project investment and project risks consequently. General method used in the tunnel geophysical survey techniques are seismic refraction, seismic surface wave method, and high-density electrical sounding method, etc, but these methods have shallow detection depth, slow speed, terrain impact, low precision and other issues. Controlled source audio-frequency magneto telluric method, referred as CSAMT method is an electromagnetic exploration method developed rapidly in recent years, which use the difference of electrical conductivity of rocks to observe the changes in EM field strength, it has many advantages: first, it used source coupe controlled, measured parameters for the ratio of electric and magnetic fields - canards resistivity, enhanced anti-jamming capability and reduce the impact of the terrain as a result; second, it use the changes in the frequency instead of changing the geometric dimensions sounding at different depths, which can launch multiple points to complete the electromagnetic sounding at one time ,resulting in improved efficiency; Third, probing depth range generally up to 1 ~ 2km; Fourth, the high lateral resolution can be Sensitive to find fault; Fifth, high resistance shielding effect is little, can penetrate the high resistance layer. Because of this, CSAMT method engineering exploration in recent years has achieved good results. Ref. 4 briefly describes the current overview research of long deep tunnel investigation and research first, and then discussed the impact by static

effects caused by physical and topographical object and the correction methods, such as one-dimensional spatial filter, two-dimensional modelling method, electromagnetic array profiling, phase data correction method and so on.
After excavation, radar detecting results and real geological environments are relatively uniform through practical examples. In this paper, we take the example of the advanced geological forecast of railroad to present the application of GPR for geological disasters in tunnel construction.
GPR uses short pulses of electromagnetic waves that are propagated into the ground by a transmitting antenna that is placed on the ground surface. At the same time, a receiving antenna detects the waves that are reflected up to the ground surface when the transmitted pulse encounters a subsurface interface across which exits an electromagnetic impedance contrast. The delay between the transmitted pulse and the arrival of a reflection is proportional to the depth of the subsurface feature that generated the reflection. Figure 1 shows the GPR system.

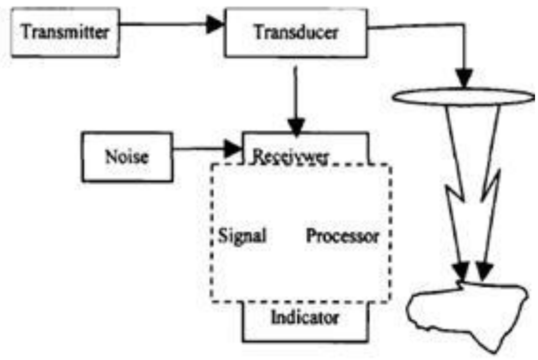

Figure 1: The model blocks diagram

GPR has been used successfully for detecting groundwater, locating underground karst caves, and for mapping stratum features in shallow subsurface geological structures. The main surrounding rock in the landslide section is composed of the K1 sandstone and carbonaceous slate. Subjected to the transformation of dynamometer Orphism, the structure of the sedimentary rock had been changed in varying degrees. There were a lot of joint and fissures in the surrounding rock.
There were two kinds of clasps in the landslide body: One was the crush breccia whose main ingredient was sandstone. The shape of most of the fault breccia was platy and schistose. The particle size of clasps ranged from 1.5cm-40cm without rounding and sorting. The clearly scratches were visibly on the surface of some individual debris. Another was the fault gouge which was consisting of the soft, unconsolidated and dusty rock fragments. It filled in the gap between the fault breccia in the fault zone or covered the surface of the fault breccia partially. (Zhang, 2016)
Being made of K1 sandstone, the fault plane was flat and smoothly with the clearly scratches on the surface. From left to right, the depth of scratched was from deep to shallow. The attitude of the fault plane was 75-50 and extended stability whose width was 15m-20m.
There was abundant fissure water in the surrounding rock of the landslide section. The distribution of groundwater was controlled by the geological structure. Various tectonic structural planes constitute the main water-bearing structure. In the role of the current tectonic stress field, most of the compressive structural plane in the echelon fracture zone occurred tensile and formed the space of the groundwater-flow. As the lower pressure in tunnel, the groundwater would flowed to tunnel .by the way ,the groundwater infiltrated the fault breccia and the fault gouge， soften the cement on the rock surface ,increased the specific gravity of rock and reduced the strength of structural plane. Ultimately, abundant groundwater in the fault zone accelerated the instability of the surrounding rock.

3. Abundant Groundwater in the Fault Zone Accelerated the Instability of the Surrounding Rock with TSP and GPR

There was abundant fissure water in the surrounding rock of the landslide section. The distribution of groundwater was controlled by the geological structure in tunnel. Various tectonic structural planes constitute the main water-bearing structure. In the role of the current tectonic stress field, most of the compressive structural plane in the echelon fracture zone occurred tensile and formed the space of the groundwater-flow. As the lower pressure in tunnel, the groundwater would flow to tunnel. By the way, the groundwater infiltrated

the fault breccia and the fault gouge, softens the cement on the rock surface, increased the specific gravity of rock and reduced the strength of structural plane. Ultimately, abundant groundwater in the fault zone accelerated the instability of the surrounding rock.
On the basis of analysing the tectonic joint collected at the scene with Schmidt net, there were three groups tectonic structure plane: the attitude of the first group of the tectonic joint was 760,its strike paralleled to the echelon fracture and intersect with the 5# inclined shaft of the tunnel at 280angle. The attitude of the other two groups of the shear joint were 800, both of them were belong to a set of conjugated joint whose acute bisector was parallel to the axis of maximum stress (al) of the present tectonic stress field in tunnel. The strike of acute bisector was 3420^3460 which is shown in Figure 2.

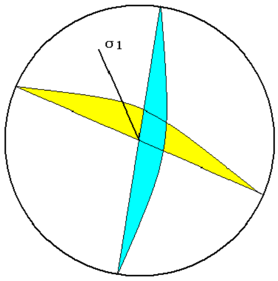

Figure 2: The model blocks diagram

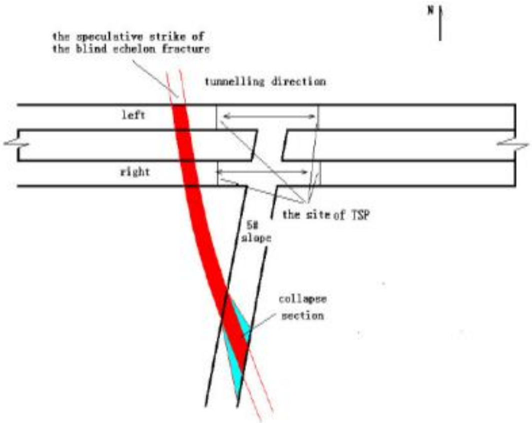

Figure 3: The model blocks diagram

Under the control of the present tectonic stress field, it was very unstable that the echelon fracture expressed as tensile structural plane. Figure 3 showed the result obtained from studied the relationship between the landslide location and the tunnel that the echelon fracture intersect with the 5# inclined shaft of tunnel at low angle and the main tunnel at wide angle. It was speculated that the group fault structure would be likely encountered as the tunnelling into the main tunnel which is shown in Figure 3.
As the main geological structure control collapse, the extending longer echelon fracture had experienced several tectonics. Under the role of the tensile stress, the rock which had been very broken in the fracture zone formed the unstable geological rock.
While the lower pressure space has been become in tunnel, the groundwater would flow to tunnel. By the way, the groundwater infiltrated the fault breccia and the fault gouge, softens the cement on the rock surface, increased the specific gravity of rock and reduced the strength of structural plane. Ultimately, abundant groundwater in the fault zone accelerated the instability of the surrounding rock and led to the collapse occurred.
Along the tunnel wall a sequential detonation of small charges embedded in the rock creates acoustic signals, which propagate on spherical wave fronts through the rock mass. Changes in rock strength (acoustic impedance) as they occur for example at fracture zones, at karst cavern, at karst collapse column, at groups of joints, at changes of rock formations and so on, will reflect a certain portion of the signals, whereas the remaining portion will be transmitted. The time taken for the reflected signals to arrive back at the highly sensitive receivers is measured. By analysing the wave propagation velocity in the rock formation the travel time of the reflected signal can be converted into a distance (depth). As a result, the location of the rock discontinuity, the intersection angle to the tunnel axis and the distance to the tunnel face can all be determined.
In most cases, according to results from geological investigation, the positions of the receiver casing (steel tubes) and shot holes have been defined. The TSP method builds on this information by predicting more accurately where these changes will occur.
The 24 shot-points wound are arranged in the selected tunnel wall which is shown in Figure 4. All of the shot-points should be radial to the tunnel axis, inclination 15-200, perpendicular to wall, diameter 38 mm. the interval between shot-points should be approx. 1.5 m, In any case the interval should not exceed 2m. The number of shot-point must be more than 18 for each TSP measurement. The receiver hole should be located in the same tunnel wall which the 24 shot-points had been arranged. The distance between the receiver and the first shot-hole should be in the range of 20 m, in any case not less than 15 m. the height of shot-points and

receiver borehole was approximate 1 m above tunnel floor. The receiver hole should be radial to the tunnel axis, inclination 15-200, perpendicular to wall, diameter 55 mm.

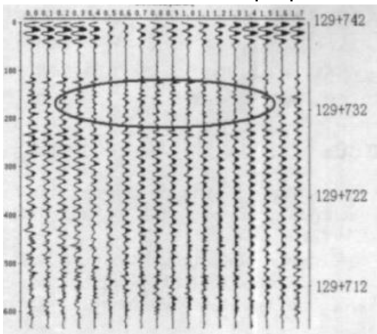

Figure 4: The 24 shot-points wound are arranged in the selected tunnel wall

Setting the receiver casings with epoxy cartridges should preferentially be carried out just after having drilled the receiver holes. Fill the borehole with sufficient number of cartridges to ensure the casing is held firmly in place. Three cartridges are usually sufficient for each casing if the borehole diameter does not exceed 45 mm. Check with the receiver casing whether the bore hole is straight and shows the required size before setting the receiver casing with the cartridges.

4. Experiment Result and Data Analysis

While analysed velocity of the surrounding rock and created velocity model the velocity models of P-component, SH-component and SV-component, we found there were several dense zones of reflector. There are three dense zones of reflector at DK293+635, K293+616, DK293+592, K293+576, DK293+562, K293+54. 6 in the TSP detection map of left tunnel of tunnel in direction which is shown in Figure 5.
There are three dense zones of reflector at DyK293+643, yK293+623, DyK293+598, yK293+572, DyK293+565, yK293+558 in the TSP detection map of right tunnel of the tunnel in direction.
It was obviously that not all of these abnormal dense zones of reflector are large blind geological structure. According to the multiple solutions of the results of geophysical prospecting, we have completed the secondary image extraction of the blind geologic body on the basis of a detailed study of the geological characteristics analysis of the echelon fracture in 5# inclined shaft of the tunnel. Using the engineering geological model of collapse, we can preliminary predict the intersecting position where the echelon fracture controlling on the collapse would be intersecting with the tunnel. So during TSP advance detection, we focus on looking for abnormal image in the section from the result of TSP survey.
The results of TSP detection on both tunnels indict that there is a joint intensive belt on the corresponding position composed of the two groups of the strong reflection plane interlacing together. It is the reflected image of the echelon fracture controlling on the collapse whose influence width of the joint intensive belt almost is 19m^20m (DK293+635, K293+616 in left tunnel and DyK293+643, yK293+623 in right tunnel). Thus, we conclude that there is a blind echelon fracture in front of face (DK293+660) and the distance is about 20m which is shown in Figure 6. The conclusion has been proved by the evidence including the geological sketch, the weakening of the mechanical properties of rock, the increasing of structure plane's number and the variation of groundwater's flow. The accuracy of the TSP prediction being listed in the table 2 has been tested and verified in the process of the tunnel excavation lately. In most case, the error of the TSP prediction for the blind structural plane intersects with the tunnel at wide angle within 100 m--150m ahead of the face is no more than 2m. The multiple solution of the geophysical resultant map has been maximum reduced.

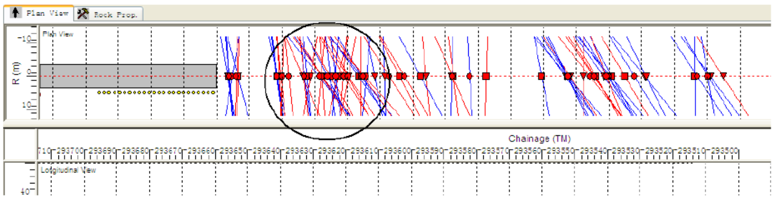

Figure 5: The map of the velocity models in left tunnel of the sample

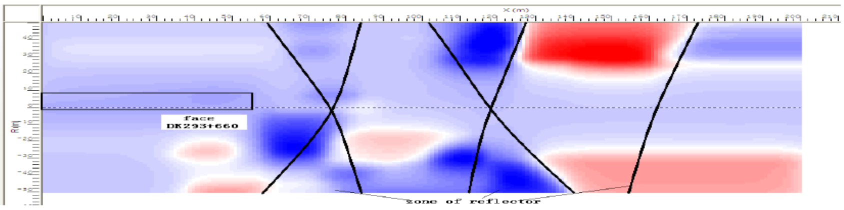

Figure 6: The TSP result map of blind echelon fracture in front of face in right tunnel of the sample

5. Conclusion

In this paper, the author researches on the tunnel engineering geological exploration system based on ground-penetrating radar. This paper complete exploration system design and production. System consists of adjustable signal source, voltage acquisition device, channel switching device, communication devices and current monitoring device. Exploration device is applied to experimental. There was abundant fissure water in the surrounding rock of the landslide section. The distribution of groundwater was controlled by the geological structure. Various tectonic structural planes constitute the main water-bearing structure. In the role of the current tectonic stress field, most of the compressive structural plane in the echelon fracture zone occurred tensile and formed the space of the groundwater-flow.

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