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Geological defect and its geophysical prediction method in Karst Tunnel

***Abstract**. With the rapid development of traffic tunnels construction in mountain area in the world, hydrogeological conditions are becoming unprecedentedly complex, water inrush and mud gushing is one of the typical common geologic hazards for the karst tunnel construction. .Based on the analyzing karst tunnel water inrush examples in recent years in china, the mechanism of geologic structure for water inrush has been explained through analyzing different karst hydrogeological storage structures. The unfavorable geologic bodies can be forecasted by geophysical method, and the detecting device and the signal receiving sensor would be selected for different water-bearing structure. The seismic wave, electromagnetic wave will be reflected and received by sensor when encountered geological defect, and the attributes of unfavorable geologic bodies were identified based on the returned signal. Risk assessment of water inrush must be done firstly during tunnel construction, an optimal system for water-bearing structure detecting in which prediction methods vary with the risk level of water inrush can be probed. As a result, the hazard prevention & controlling technological system of water inrush of karst tunnel is composed of risk evaluation system and comprehensive geological prediction system. It has been successfully used for hazards prevention and control for water inrush of Qiyueshan Tunnel in Hurong highway, including risk assessment and hazard source detection. Conclusions will benefit further research on hazards control of underground construction.*

Streszczenie:** Wraz z szybkim rozwojem budowy tuneli w terenach górskich rośnie znaczenie oceny warunków hydrogeologicznych: W szczególności, w przypadku tuneli w terenach krasowych, typowym niebezpieczeństwem jest napór wody i tryskające błoto. Na podstawie analizy wypadków w tunelach krasowych w Chinach w ostatnich latach, wyjaśniono mechanizm naporu wody przez analizę różnych formacji hydrogeologicznych w obszarach krasowych. Niekorzystne warunki geologiczne można prognozować metodami geofizycznymi, przez zastosowanie urządzenia detekcji sygnałów odbitych od różnych struktur wodonośnych. Podczas projektowania tunelu należy ocenić ryzyko wystąpienia naporu wody i przeprowadzić wszechstronną prognozę geologiczną. Przy budowie tunelu Qiyushan linii kolejowej Hurong przeprowadzono badania obejmujące oszacowanie ryzyka i wskazano źródła niebezpieczeństw. **Defekt geologiczny i jego geofizyczna prognoza w tunelach krasowych

Keywords: Geological defect, detecting device, sensors.
Słowa kluczowe: Defekt geologiczny, Układ detekcji, Czujniki

Introduction

Due to the implementation of western development strategy, the tunnel construction in China are rapidly developing with the largest number and the widest scale in the world. Especially with construction center of hydraulic-hydroelectric engineering and railway-highway engineering transferring to western mountain areas with complex terrain and geological conditions, many long tunnels with the characteristics of deeply buried, long line, karst development, high water pressure, complex structure, high risk of water inrush, more difficult construction come forth. The hydrogeological conditions in tunnel construction areas become more complex and types of abrupt geological hazard become more varies, as well as the forming mechanism and control method, especially to inrush of clay and water accident caused by large water-bearing structure and bad geology. Clay and water inrush threats caused by deep environment of abundant water, high pressure and high geo-stress become more serious with increasing buried depth, section size and line extension of the tunnel. In particular, the buried depths of some tunnels have exceeded 2500 m, and water pressure is over 10 MPa. Problems of abrupt clay and water inrush hazards with high pressure and large capacity are destructive dynamic phenomenon. Therefore, accurate prediction and effective governance of karst water-bearing structures become major engineering problems to be solved urgently [1,2].

However, single method with detecting seniors cannot forecast geological defects accurately. Comprehensive prediction is a common method to improve the forecast effect[3], but the existing methods usually are simply combined with a variety of single method, which the effect and efficiency is non-ideal. To realize the accurately forecast of different water-bearing structures, advanced geological prediction schemes were determined using the risk assessment of water inrush. The feasibility and practicality of the prediction scheme presented in this work is demonstrated with the application in the prediction of water inrush in Qiyueshan Tunnel of Hurongxi Highway.

Types and Water-Bearing Structure Forms of Water Inrush

(1) Types of water inrush

Based on the statistics of the examples of water inrush of tunnels, there were about 100 tunnels occurring water inrush in the last 50years (see Tab 1). In China there existed about 97 major security incidents in tunnel engineering from 2001 to 2010. The incidents caused by mud bust and water inrush owned about 77.3%.

Table1 Incidents of water inrush and mud burst of tunnels since 2000

Years	Tunnel	Numbers of water inrush and mud gushing	Numbers of death and missing	Inducement of disaster
2001~2004	Yuanliangshan Tunnel	71	9 (death)	Buried filling solution cavity
2002~2003	Tongyu Tunnel	10	3(death) 2(missing)	Karst development and solution cavity
2004~2008	Maluqing Tunnel	19	11(missing)	Underground river and groups of solution cavity
2004~2008	Yesanguan Tunnel	20	3(death) 7(missing)	Underground river and groups of solution cavity
2006~2010	Tianchi Tunnel	12	3(death)	Long karst development zone
total		132	38	Major geological disasters source

1) Water inrush of faults

The water content is large and the water recharge conditions are good in the formation of faults. Because of the head difference the flow makes the water conductive fault connected or actives the water blocking faults. Then the flow will burst into the tunnel along the faults.

2）Water inrush of karst conduit

The karst conduit is usually filled with media. If there is a large amount of water near the conduit the filling material will become unstable when the mechanical conditions of the geological defect is in the critical conditions of water inrush. Then under the strong osmotic pressure and excavation perturbation the material is destroyed. The water inrush pathway is formed.

3）Water inrush of fracture

Fracture owns the characteristics of water conductivity and water storability. When the fracture is revealed or the fracture extends to connect the confined aquifer water inrush will occur.

4）Other kinds of water inrush

The type of water inrush comprises of any two or three types of fault, karst conduit and water inrush of fracture.

(2) Forms of water-bearing structure4

1) Water storage in fracture-karst

Groundwater produces dissolution when flowing along bedding fissure and joint fissure. The fissures are widened, forming the forms of water storage in fracture-karst, and making the strata in soluble rock high water permeability and water abundance. Local water-rich structure is easy to form at kinked parts, axis of syncline and anticline or the fold parts. For example, the Maoba syncline part in Yuan liangshan tunnel in Yuhuai line is the form of water storage in fracture-karst. There were five tunnels in Chengkun line through Mishi syncline breaking out of water gushing disaster in different degrees.

2) Water storage in dissolved cavity and dissolved sink

In the Karst region, the hidden dissolved cavity and dissolved sink usually store a lot of water. Once they connected to nearby hydrographic net, large water supply system would be formed. For example, large water gushing disasters occurred during the construction of Malujing tunnel because the surrounding rock was fractured by the dissolved cavity water. There were totally five large water inrush disasters caused by dissolved cavity water which connected to large underground river.

3) Water storage in fault

The rock on both sides of the fault plane is crushing. It not only has water-storage space, but also is the influx channel of pore water, fissure water and karst water. The uncemented tectonic belt and derived tectonic belt in active faults often form fault aquifer structures. For example, the Dayaoshan tunnel in Jingguang railway through F9 fault broke out of Gushing disaster repeatedly. The Nanling tunnel broke out of large water inrush disaster because of exposing the karst fault in the construction.

4) Water storage in underground river and karst conduit In the mixed flow belt, the lay and fracture can form big water storage of underground river and karst region through the dissolution and erosion of the groundwater during long geologic time. Such as a great deal of water in the local of karst conduit through carbonate rock bottom revealed during the construction pouring into the Huayingshan tunnel in Guangyu line. Three big underground rivers were revealed during the construction of Wulong tunnel in Yuhuai Railway, leading to large water gushing disasters.

5) Karst water storge form between interlayer

Karst water storge form between interlayer which is similar to fault septation type water storage, is a water storage space structure mainly by karst dissolution between interlayer. This structure between the thickness of soluble rock can be limited. Most of the isolation water rock are shale, sandstone, limestone et al. This region is easy to form rich water near the strip, such as,Jing-Tong line taoshan tunnel occurred gushing water in the contact zone of the crossing limestone beyond gneiss and mylonite. Furthermore, Nan-Kun Line passed through Karst mountain carbonate and classics transfer of parts of a large number of karst springs exposed, where was easily happened water gushing disasters

6) Combination type water storage form

In the karst area, there are many underground rivers and karst water pipe forms, concealed solution cavity and solution sink water storage form. Once it produced water gushing disasters, may have the high incidence, sudden, rich water and rich sediment characteristics. The groundwater system presents reticulation, the water storage form each other between existing hydraulic contact, the dominant form of water gushing water is not clear, and in combination of the power source of water gushing appear. Furthermore， there will be some other types of water storage in the form in karst tunnel construction, this paper is no longer tired narrate.

Key Controlling Technology For Water Inrush

In the perspective of prevention and controlling, the prevention technology system for water inrush hazard in karst tunnel is established, consisting of three parts: risk assessment, comprehensive prediction methods.

(1) Risk assessment system of water inrush

Based on risk evaluation model of water inrush, management system of construct permit mechanism can be established to reduce the economic loss and water inrush risk. The major factors are summarized and selected as the influence factor of FAHP by collecting and collating information of water inrush examples of karst tunnels in recent 50 years, the membership function is proposed between the factors and the probability of occurrence of water inrush and its volume. Meanwhile, a FAHP model of risk assessment for water inrush is established by a comprehensive assigning method used to determine the weight of evaluation indices[5].

(2) Comprehensive geological prediction system

The comprehensive geological prediction system is established based on the risk level of water inrush, as shown in Table.2, and different prediction method should be selected for different unfavorable geological bodies. Electromagnetic methods are suitable for the prediction of underground water, while Seismic method can be used to predict the geological structural plans and fracture zones.

Table2 Comprehensive geological prediction system based on risk assessment of water inrush[6]

Risk Grade	Comprehensive geological prediction system	
	Major method	Auxiliary method
I	TSP	GPR, L-ABD, S-ABD
II	TSP	GPR, S-ABD
III	TSP	GPR
IV	TSP	-------

Fig1 TSP203plus high sensitivity sensor

The seismic wave spread around with spherical form in rock, and it will be reflected when it encountered unfavorable geological bodies. The received signal will be converted into electrical signal by TSP203plus high sensitivity sensor (see Fig.1), then the location of the reflecting surface, the angle with the tunnel axis and the distance will be determined.

Engineering Application

(1) Project overview

Qiyueshan Tunnel goes through the Permian and Triassic stratum, and passes through Kangjiadacao Fault, Qiyueshan Fault and Qiyueshan anticline, as shown in Fig. 2. P2w and P2c represent a thick layer of dolomite and bioclastic limestone, which are middle-developed karst stratum. T1d represents a layer with both thick and thin layers of limestone, and karst is respectively medially and weakly developed. T1j consists of three layers of pure and thick limestone with the thickness in the range 50 m to 150 m, T1j is the most important strongly-developed Karst belt in this area.

(2) Risk assessment of water inrush

The risk assessment of Qiyueshan is summarized, as shown in Table 3.

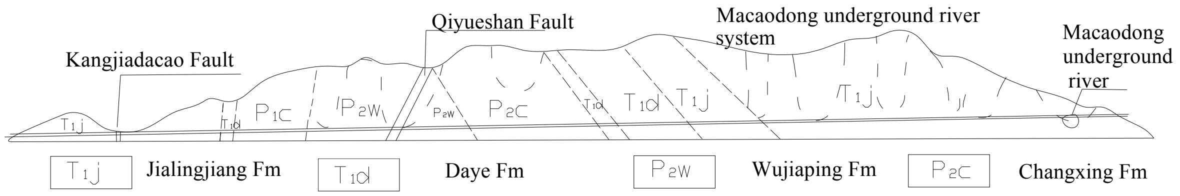


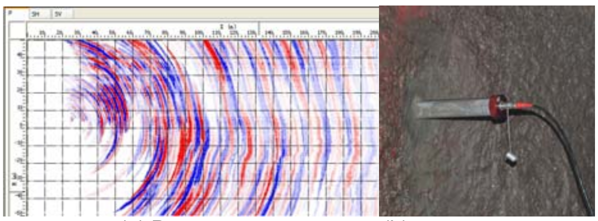
Fig2. Geological profile of Qiyueshan Tunnel[7]

Table3.Risk evaluation results of Qiyueshan tunnel[6]

Assessment Section	Risk Grade	Assessment Section	Risk Grade	Assessment Section	Risk Grade
YK326+055~YK326+800	IV	YK327+700~YK328+250	III	YK328+750~YK329+100	I
YK326+800~YK327+080	III	YK328+250~YK328+400	I	YK329+100~YK329+700	II
YK327+080~YK327+700	III	YK328+400~YK328+750	II	YK329+700~YK330+106	III

(3) Comprehensive geological prediction

For the section YK329+700-YK330+106, TSP was adopted to predict the unfavorable geological bodies, According to the measured results, several karst conduits and fissures filled with water were detected (see Fig.3).

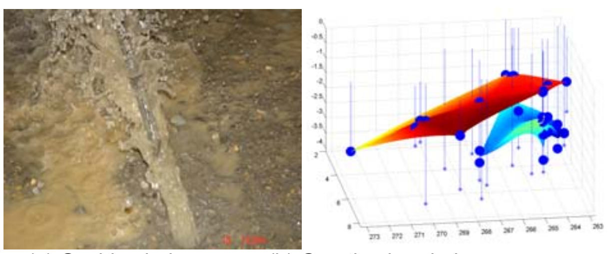


(a) P-wave (b) sensor

Fig3. Reflection profile of P-wave and TSP sensor

(4) Grouting treatment of water inrush

According to the analysis of the comprehensive geological prediction results, the layout scheme of grouting boreholes was determined (see Fig. 4), which can strengthen the whole water inrush district and ensure the safety of the tunnel during the construction and long-term operation.



(a) Gushing hole (b) Grouting boreholes

Fig4. Arrangement of grouting boreholes for gushing

Conclusions

(1) Based on the statistical analysis of a large number of cases of water inrush in karst tunnels, water inrush types are divided into water inrush of faults, water inrush of karst conduit, water inrush of fracture and other kinds of water inrush. The mechanism of geologic structure for easy water gushing has been explained through the analysis of different karst hydro-geological storage structure, such as forms of water storage in fracture-karst, forms of water storage in dissolved cavity and dissolved sink, forms of water storage in fault, forms of Water storage in underground river and karst conduit, forms of karst water storge form between interlayer and Combination type water storage form.

(2) Physical detection method and technology was proposed for different water-bearing structure, and the prediction schemes were modified based on the risk assessment of water inrush so that they were more pertinence and practicality.

(3) Hazard prevention & controlling technological system was established for karst tunnels' water inflow and inrush. It was successfully used for risk assessment of water inrush, controlling of hazard-causing bodies for Qiyueshan Tunnel.

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