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Cause Analysis of Intermittent Water and Mud Inrush in Chaoyang Tunnel

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Abstract

In order to study the geological causes of intermittent water and mud inrush in Chaoyang Tunnel of Guinan High-speed Railway, the sieve test, psephicity analysis and mineral composition detection of filling medium were carried out. The failure mode of water and mud inrush was studied, the groundwater source of water and mud inrush was determined, and the causes of water and mud inrush in Chaoyang Tunnel were put forward. The results show that: the particle gradation curve of the filling medium is gravel type, and the failure mode of the first water and mud inrush in the tunnel belongs to the seepage instability type. The particle roundness of filling medium is good, and the main content of mineral composition is quartz. There is a hydraulic connection between the revealed karst cave and the underground river. The karst cave water, the underground river and the surface rainfall are the main sources of water inrush. There is a recharge relationship between the Yudanshan reservoir and the groundwater system where the water and mud inrush are located. The research results provide a useful reference for the treatment of intermittent water and mud inrush disasters in Chaoyang Tunnel.

Keywords

Karst tunnel; Intermittent water and mud inrush; Water source; Disaster geological causative; Rainfall.

1. INTRODUCTION

With the vigorous development of the economy and the continuous improvement of infrastructure, China 's tunnel and underground engineering has been highly developed, and has become the world 's largest, fastest and most difficult country for tunnel and underground engineering construction [1]. The geological environment faced by tunnel construction is also increasingly complex. Strong karst, large buried depth, high ground pressure and extremely complex geological structure leads to frequent water and mud inrush disasters, which seriously threaten the safety of life and property of construction personnel and the progress of the project [2,3] Intermittent water and mud inrush refers to a special phenomenon that two or even multiple water and mud inrush occur in the same location of bad geology. It is a highly disastrous water and mud inrush mode. In construction, serious casualties and economic losses are often caused by ignoring the occurrence of secondary water and mud inrush disasters [4-5]. From November to 26,2019, an intermittent water and mud inrush disaster occurred in Anshi Tunnel [6] of Yunfeng Expressway in Yunnan Province. The first water and mud inrush was about 3 000 m3, resulting in 5 construction workers buried and 1 construction worker trapped. The on-site construction workers spontaneously carried out rescue. About 1 hour later, the second water and mud inrush occurred, with about 12 000 m3 of mud inrush and about 800 m3 of water inrush per hour. As a result, 7 people who spontaneously participated in the rescue

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and the first water and mud inrush trapped construction workers were lost in danger, and 9 people were rushed out of the tunnel. A total of 12 people were killed and 10 people were injured in the two water and mud inrush, and the direct economic loss was about 25.25 million yuan. In addition, intermittent water and mud inrush disasters have occurred during the construction of Xianglushan Tunnel[7], Baiyun Tunnel[8] Shangjiawan Tunnel[9], Liangshan Tunnel[10], Niulangang Tunnel [11]and so on. It can be seen from the above cases that multiple water and mud inrush disasters in the tunnel have brought serious economic losses to the tunnel construction.

Aiming at the large-scale intermittent water and mud inrush disaster of PDK170 + 671 at the outlet of Chaoyang tunnel of Guinan high-speed railway, the disaster-causing characteristics of intermittent water and mud inrush in karst cave are analyzed. By studying the particle gradation, roundness and mineral composition characteristics of karst cave filling medium, combined with the characteristics of intermittent water and mud inrush and the hydrogeological conditions of tunnel site, the causes of water and mud inrush in Chaoyang tunnel are revealed, and the source of groundwater is determined. The research results can provide reference for similar engineering disaster analysis.

2. PROJECT PROFILE

The main line of Guinan high-speed railway is 482 km, and the total length of the tunnel is 257.5 km. The length of the karst section of the whole line accounts for 68.2 % of the total length of the tunnel. Chaoyang Tunnel is located in Dushandong-Libo Station of Guizhou Province, with a total length of 12 734 m. The tunnel containing karst cavity is easy to cause water inrush disaster, so it is of great significance to study the causes of water inrush in the tunnel. The schematic diagram of Guinan high-speed railway line is shown in Fig.1

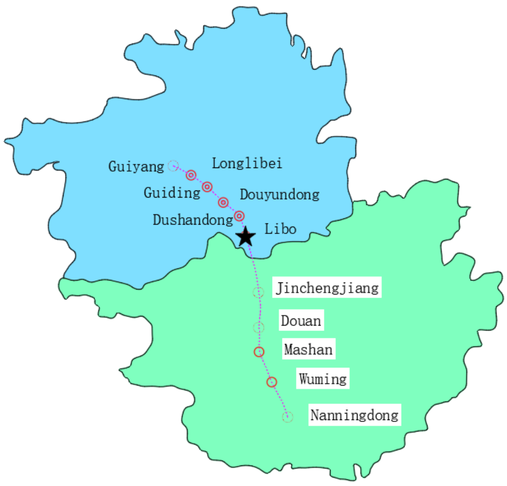

Figure 1. Sketch of Guiyang-Nanning railway

The Chaoyang Tunnel of Guinan High-speed Railway is located in Chaoyang Town, Libo County, Guizhou Province. The starting and ending mileage of the tunnel is DK159 + 802-DK172 + 536, with a total length of 12 734 m and a maximum buried depth of about 386 m. The tunnel is a double-line single-hole, with ' 2 horizontal 1 inclined 2 flat, and a flat guide is provided at the exit for drainage during construction and operation., and the geological section of the water and mud inrush section is shown in Fig.2.

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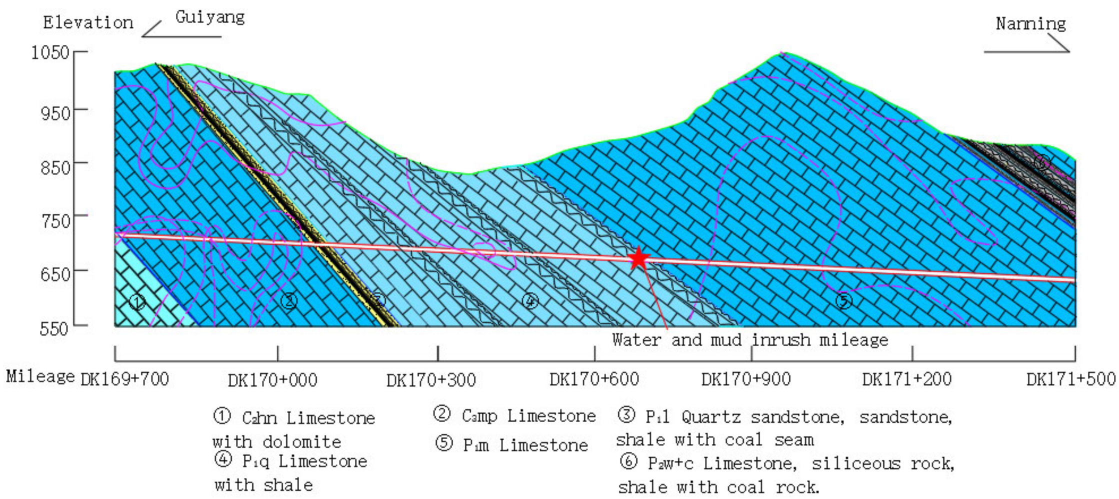

Figure 2. Geological map of water and mud inrush section of the tunnel

2.1. Topography

The landform of the tunnel site belongs to the middle and low mountains and peak cluster valleys. The terrain is undulating and the vegetation is developed. The absolute elevation is 465 ~ 1105 m, and the relative height difference is up to 700 m. The natural slope is generally 20 ~ 55 °, and the local cliff is formed. The entrance and exit of the tunnel are reached by road, and the traffic conditions are good.

2.2. Stratum lithology

The tunnel site area is covered by Quaternary Holocene slope residual layer ($Q_4d^1 + c^1$) silty clay and clay, and the underlying bedrock is : Upper Permian Changxing Formation + Wujiaping Formation ($P_3w + c$) medium-thick layered limestone, siliceous rock, shale and coal seam ; middle Permian Maokou Formation (P_2m) thick-thick layered limestone Qixia Formation (P_2q) thick layered limestone intercalated with shale, Liangshan Formation (P_1l) quartz sandstone, sandstone, rock intercalated with coal seam ; upper Carboniferous Maping Formation (C_3mp) thick layered limestone ; middle Carboniferous Huanglong Formation (C_2hn) thick layered limestone with dolomite ; the thick limestone in the upper member of the Lower Carboniferous Datang Stage (C_1d^2), and the shale in the upper member of the Lower Carboniferous Datang Stage (C_1d^1) with argillaceous limestone and carbonaceous shale ; the argillaceous limestone of the lower member of Jiusi Member (C_1d^1) of the Lower Carboniferous Datang Stage is interbedded with shale, carbonaceous shale and sandstone.

2.3. Geological structure

According to the regional data and field investigation, the structure of the tunnel passing through the area is a water conservancy anticline. Affected by the regional structure, three secondary fault layers are developed in the tunnel section, namely, Di'e 1 # reverse fault, Mercury normal fault and Chaoyang reverse fault. The Di'e 1 # reverse fault has an angle of 21 ° with the line. The surface is near the mileage DK162 + 665, with a trend of N63 ° Wand a tendency of NE. The fault is not obvious near the line. The field investigation found that the lower Permian Liangshan Formation was broken. According to the actual topography and geomorphology of the site and the comprehensive analysis of geophysical exploration results, the width of the fault fracture zone is about 60 m, and the influence in the tunnel is about 70 m. The mercury normal fault intersects with the line at 79 °, the intersection mileage is near DK168 + 400, the strike is about N53 ° E, and the tendency is SE. There is no obvious sign of the fault

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near the line, and the attitude of the rock strata on both sides of the fault changes greatly. Chaoyang reverse fault is a fault on the regional geological map. Due to the development of vegetation, the signs of the fault near the line are not obvious. Combined with the results of geophysical exploration, the fault intersects near the mileage DK172 + 023, strikes N36 ° E, intersects with the line at 45 °, and affects about 100 m in the tunnel.

2.4. Surface water system

The rivers in Libo belong to the Longjiang River system in the Pearl River Basin. There are larger water systems in the county. Dagou River system, Sancha River system and Jialiao River system. The water system that the tunnel passes through belongs to the Dagou River system.

2.5. Water-bearing rock group and groundwater type

The groundwater is mainly composed of pore water, bedrock fissure water and karst pipeline water in the Quaternary soil layer. The water volume is medium, which is recharged by atmospheric precipitation and surface water, and is discharged in the form of surface runoff, spring and underground river. The pore water mainly occurs in the Quaternary Holocene slope residual layer and the bedrock weathering layer at the inlet and outlet of the tunnel area. The water content is relatively poor, and it is mainly recharged by atmospheric rainfall and surface water. Bedrock fissure water mainly occurs in non-soluble rock strata, with weak content. It is rich in fissure water in bedrock only in the activity of geological structure, fracture and structural joint fissure development zone. In the dense joint zone or near the fracture zone, the groundwater is large and the water is rich. Tunnel construction near joint fissure dense zone or fracture zone may encounter strand water gushing. Part of the tunnel surrounding rock is soluble rock, and the ground water belongs to karst fissure-pipe water. Due to the development of surface depressions, sinkholes, karst caves and sinkholes, it is speculated that the karst in the tunnel area is medium-strongly developed, the karst water is rich, and the water-rich degree is medium, but it is not uniform and the distribution is irregular. The groundwater will increase exponentially in the rainy season.

3. TUNNEL INTERMITTENT WATER AND MUD INRUSH SITUATION

On June 10, 2018, a large-scale water inrush disaster occurred at the tunnel exit guide PDK170 + 671 (buried depth of about 230m). A large number of mechanical equipment was destroyed, resulting in three deaths, significant economic losses and adverse social impacts. There are obvious geological signs and intermittent water inrush characteristics before large-scale water inrush in the tunnel, so it is intermittent water inrush. The water inrush situation of the tunnel began on May 30, 2018, and its development process is listed in table 1, and the water inrush scene is shown in figure 3.

Figure 3. Field pictures of water and mud inrush

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Table 1. Process of water inrush in the tunnel

Time (2018)		Description of the situation
may 30 th	4:30	Turbid water gushed out from the central borehole of the tunnel floor, and the pressure gradually increased. The spray distance was about 10 m.
	6:00	The gushing water changes from turbid to clear.
	8:30	Stop the water, the water point around the horizontal drilling detection has not water.
	9:00	Turbid water appeared when two blastholes in the bottom plate were redrilled, and the spray was about 10 m.
	9:00-12:00	The gushing water becomes clear, but the water pressure of the gushing water remains unchanged.
	12:00	Eight horizontal boreholes above the water outlet point were detected. Three holes at about 40 cm above the bottom plate produced turbid water. The spray distance was about 15-20 m. The water inflow in the hole was about 744 m^3 per hour. It did not decrease but had a tendency to become clear. The tunnel face was stable, and the gushing water drained down the slope by itself.
May 31th		Carry out advanced geological prediction near the water inrush point
May 31-June 1		With continuous rainfall on the surface, the hourly flow rate in the cave gradually increases from 570 m^3 to 1100 m^3 and then tends to be stable.
June 2th		Four drilling holes were drilled on the face of the tunnel. One hole was drilled to 5 m when the water came out, 20 cm burst at 8 m, and the drilling could not be stopped at 10 m.
June 3th	-	The fourth borehole drilled to 8.5 m of water.
	0:30	After the drill pipe is withdrawn, the jet distance reaches 12 m
	0:48	From May 30 to June 3, the water inflow is about 105 m^3, and the flow in the cave changes with rainfall.
	11:40	Blasting reveals the development of karst: there is no water on the face of the tunnel, and the mucking begins to occur.
	13:50	Sudden gushing of water when the last ballast, water inflow of about 30 000 m^3 in 2h.
	15:40	The water inflow stops, only a small amount of water flows out slowly, and the water inflow and water quality are stable.
June 4th		Dredging, easy to close and further find out the geological conditions of the tunnel face.
June 5th		Sectional dredging, construction of sand dam at 150 m of the working face
June 7th		On the right side of the floor, there is a solution gap of about 2m long and about 0.5m high, with fine water flowing out slowly and no pressure. From 300 m to the entrance of the tunnel, the side wall shows that the immersion height is 20 ~ 40 cm.
June 8th		Determine the treatment plan, strengthen the monitoring and measurement, carry out the geological radar detection of the working face, the horizontal drilling of the right side wall and the drilling exploration around the cave.
June 9th		Advanced horizontal geological drilling was carried out in the side wall to the main hole, and there was a situation that the drill could not be drilled.
June 3 ~ June 10		Shut down in the tunnel, dredging in order to carry out advanced geological prediction; the surrounding rock of the tunnel face is stable, and a small amount of non-pressure water has been slowly flowing out of the exposed solution gap, and the water quantity and water quality are stable. It is planned to level the floor on June 10 to carry out floor geological radar detection.
June 10th	8:30	The water outlet point of the tunnel face is slowly flowing water, the water quantity and quality are not unchanged, and there is no pressure.
	9:56	Sudden large-scale water and mud inrush, the water level height is about 2.5 m above the bottom plate, which lasts for about 1 h and then returns to the previous normal water output. The water inflow is about 57 000 m^3, which is concentrated in 30-40 minutes. The flow rate is about 25 m^3 per second, and the flow rate is 2 m per second.。
	After the accident	Uncover the water inrush point, there are two halls close to the basketball court. The huge amount of water gushing suddenly and concentratedly caused three deaths. The excavation bench and 12 m secondary lining trolley in the flat guide hole were washed out of the flat guide hole by mud water, and the three fans, emergency material warehouse and duty room at the entrance of the hole were washed away and destroyed as a whole.

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The surface rainfall before water and mud inrush in the tunnel is shown in Table 2.

Table 2. Weather situation statistics before water and mud inrush

time	5.30-6.01	6.02-6.03	6.04	6.05	6.06-6.08	6.09-6.10
weather	Moderate rain - heavy rain	cloudy	cloudburst	cloudy	shower	cloudy

The water and mud inrush can be divided into the following four stages: The first stage, from May 30 to June 3 at 0: 48, belongs to the drilling water, and the water source is the static reserves in the cave cavity and the recharge of surface rainfall (the flow changes with the rainfall). The second stage, June 3, 11: 40~15: 40, blasting excavation disturbance, water inrush lags behind the disturbance by about 2 hours. In the third stage, from June 4 to June 10, before the water inrush, the construction of the tunnel face was stopped, and the dredging and advanced geological prediction were carried out in the cave. The construction disturbance was small, and the groundwater in the cave cavity was due to the large amount of groundwater in the early stage. The water pressure is reduced, and the groundwater in the cave is continuously collected and the water pressure is increased. In the fourth stage, at 9: 56 on June 10, the groundwater in the karst cave of the tunnel was continuously recharged by surface rainfall and groundwater system, and the water level rose. After reaching the critical state, the anti-outburst body was broken through, and large-scale water and mud inrush occurred.

4. CHARACTERISTICS ANALYSIS OF KARST CAVE FILLING MEDIUM

The particle size distribution, particle roundness and particle mineral composition analysis were carried out on the residues in the tunnel after the water and mud inrush in the tunnel PDK170 + 671on June3,2018. The physical properties of the filling medium were studied to provide a theoretical basis for the analysis of water and mud inrush disasters.

4.1. Analysis of particle gradation of filling medium

A screening test was carried out on the residual soil samples after water and mud inrush in the tunnel. Two parallel tests were carried out, each of which took 500 g samples and put them into a set of sieves. The aperture of the screen is 5mm, 2mm, 0.5m, 0.25mm and 0.075mm respectively. The screen is placed on the vibrating screen machine, and the vibrating time is 15 minutes. After screening, the weight of the remaining soil samples of each sieve was weighed separately. The particle size composition of the filling medium after screening is shown in Table 3 and Fig. 4, and the particle gradation accumulation curve of the filling medium is shown in Fig.5.

Table 3. Basic parameter of filling medium

Granulometric composition					
>5mm	2-5mm	0.5-2mm	0.25-0.5mm	0.075-0.25mm	<0.075mm
10.5%	31.6%	53.0%	4.3%	0.4%	0.1%

Boundary particles			Boundary coefficient	
effective size d10	constrained grain size d30	constrained grain size d60	coefficient of uniformity Cu	coefficient of curvature Cc
0.59mm	1.0mm	2.1mm	3.56	0.81

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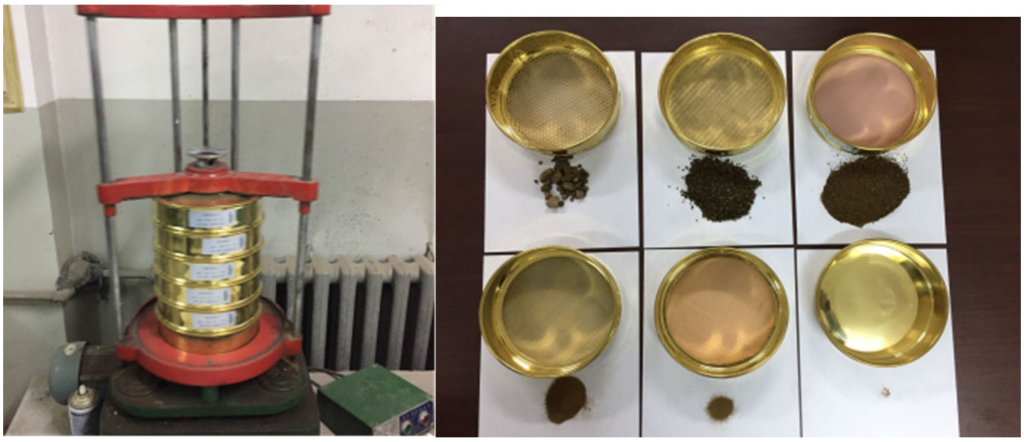

Figure 4. Pictures of sieve test

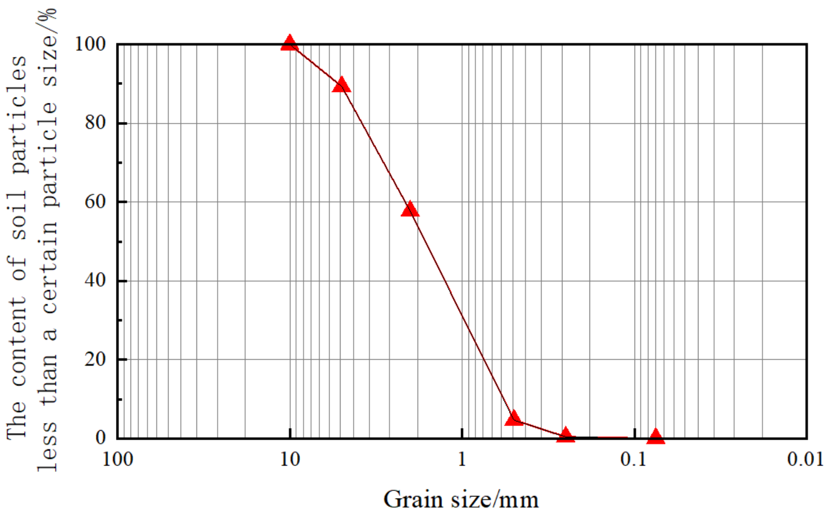

Figure 5. Cumulative curve of grain composition of filling medium

It can be seen from Table 3 and Fig.5, Fig.6 that the main composition of the filling medium soil sample is 0.5mm-5mm, accounting for 84.6 % of the total weight, the non-uniformity coefficient Cu is 3.56, the curvature coefficient Cc is 0.81, and the number of particles below 0.25mm is small. According to the field sampling results after water and mud inrush, according to the reference [12], the screening curve is close to the gravel type. This type of clay and small particles are less, and the pores between the large particle filling media lack small particle filling. Therefore, the cementation ability is weak, the structure is not dense, the porosity is large, and the permeability is strong. It should be noted that the particle gradation of the residual soil sample after the water and mud inrush of the tunnel is different from that of the undisturbed soil before the water and mud inrush, and the main difference is the fine particle content. Liu Jinquan etal[13]. analyzed the particle size distribution of undisturbed soil before water and mud inrush and soil samples after water and mud inrush in Cenxi tunnel. The undisturbed soil is close to the sediment-type filling medium, and the content of clay particles with a diameter of less than 0.075 mm is as high as 30.7 %. However, the soil sample after water and mud inrush is still a sediment-type filling medium. The particles with a diameter of 0.1mm-3mm are mainly clay particles, and the content of clay particles is only 0.9 %. The analysis shows that there is cohesion between fine particles, which is less likely to lose than 0.1mm-3mm particles. In addition, another reason is that after the loss of larger particles, it is easy to silt up in the tunnel under the action of gravity. The fine clay particles will go farther with the water flow, and even suspend in the water and be pumped out of the tunnel without silting up and inside the tunnel.

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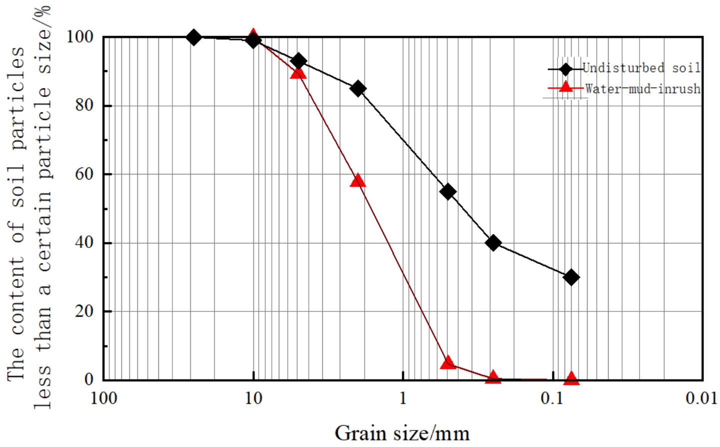

Figure 6. Gradation curve of soil in Junchang tunnel

In summary, combined with the screening results of residues in the tunnel after water and mud inrush and the change of particle gradation before and after water and mud inrush, it can be concluded that the undisturbed soil of the tunnel filling medium is close to the gravel type or the sediment type, and the fine particles occupy a certain proportion. The loss of fine particles leads to the instability of the filling medium structure, and finally the water and mud inrush disaster occurs. The second stage of water and mud inrush in the tunnel is that water and mud inrush occurs after 2 hours of blasting disturbance. According to the particle gradation and water inrush characteristics of the filling medium, it can be seen that the first water and mud inrush damage belongs to the type of seepage instability.

4.2. Analysis of particle roundness of filling medium

As one of the important characteristics of filling medium particles, roundness represents the degree of rounding of particles in the process of groundwater erosion, rolling and impact. It can be used to judge the distance of particle transport and the generation environment. It is an important basis for analyzing the source of filling medium and groundwater hydraulic connection. The roundness of the particles is related to the composition of the parent rock, the transportation distance, the particle size and the degree of crushing [14] : 1 The wear resistance of quartz sandstone, magmatic rock and limestone decreases in turn, and the rounding speed increases in turn ; the larger the transport distance, the higher the roundness of the particles, and it is easy to grind and dissolve in the early stage of transport, and the roundness changes slowly in the later stage. The rounding speed of coarse particles is faster than that of fine particles. Crushing during particle handling affects the roundness of particles. Powers [14] divided the roundness of gravel into six grades, namely, sharp-edged, angular, sub-angular, sub-rounded, rounded and extremely rounded, as shown in Figure 7.

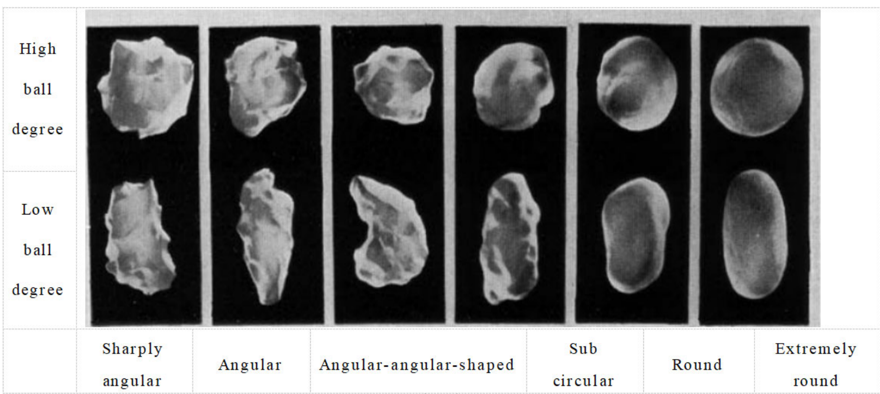

Figure 7. Roundness scale[14]

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The particle size of the tunnel filling medium is small, and most of the particle size is less than 10 mm. Therefore, the visual estimation comparison method is used to qualitatively analyze the roundness of the particles. As shown in Figure 8, the filling medium particles have different roundness, from prismatic to sub-circular. Figure 9 is a representative particle with good roundness of different particle sizes.

Figure 8. Particles of filling medium

Figure 9. Psephicity of particles in different size

It can be seen from Figure8 that the roundness of particles with a diameter of 5-10 mm is poor, generally prismatic to sub-prismatic, and individual particles reach sub-circular. The particles with a particle size of 5 mm and 2-5 mm are well rounded, sub-rounded to rounded (one of the particles with a particle size of 2-5 mm is close to extremely rounded); the roundness of particles with a particle size of 0.5-2mm is widely distributed, mainly from prismatic to sub-prism. The 0.25-0.5mm particles are smaller, and the particles have erosion and friction traces. Through the analysis of the roundness of the filling medium particles, it can be seen that the filling medium has undergone water transport and has a certain transport distance. It can be concluded that the karst cave is not isolated, but is connected with the groundwater system and is related to the groundwater force at a distance. The filling medium is deposited in the karst cave during the flow of groundwater.

4.3. Analysis of mineral composition of filling medium

The X-ray diffraction mineral analysis test was carried out on the filling medium of different particle groups of residual soil samples after water and mud inrush in the tunnel. The instrument used in the analysis test was the portable X-ray diffraction analyzer Terra-591 produced by Olympus, USA. First, the solid samples of the filling medium of different particle groups were ground and passed through a 325-mesh sieve. No less than 15 mg of the sieved powder was loaded into the sample chamber for testing, and the obtained diffraction patterns were qualitatively and quantitatively analyzed using X Powder software. The sample is shown in Fig.10, and the analysis results are shown in Figure11and Table 4.

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Figure 10. Specimens of different size soil

Figure 11. Atlas of X-Ray diffraction of different size specimens

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Table 4. Result of X-Ray diffraction of different size specimens

Sample number	1	2	3	4	5
Sample granule group	0.075-0.25mm	0.25-0.5mm	0.5-2mm	2-5mm	>5mm
Mineral composition and content (%)	Quartz (95.8) Calcite (4.2)	Quartz (98.4) Calcite (1.6)	Quartz (98.2) Calcite (1.8)	Quartz (97.9) Calcite (2.1)	Quartz (53) Calcite (47)

It can be seen from Figure10 and Table 4 that the main minerals contained in the above samples are quartz and calcite. No.1 to No.4 samples have little difference in mineral composition. The content of quartz is basically more than 95 %, and the content of calcite is very low. Although the No.5 sample with the largest particle size also contains only quartz and calcite, the content of the two is basically the same. The reason is that the filling medium mainly comes from quartz sandstone and limestone, and the No.5 sample with the largest particle size is mainly composed of sandstone and limestone with low weathering degree. With the deepening of weathering, calcite will be dissolved, decomposed and migrated. Quartz in quartz sandstone is relatively stable, only particle breakage occurs, and no new secondary minerals are produced. Therefore, the main mineral composition of No.1 to No.4 samples with smaller particle size is quartz, and the content of calcite is extremely low.

The tunnel passes through three sections containing quartz sandstone and sandstone strata, as shown in Table 5, respectively, the Permian Liangshan Formation quartz sandstone, sandstone, shale with coal seam, the lower section of the Jiusi section of the lower Carboniferous Datang stage, argillaceous limestone with shale, carbonaceous shale, sandstone, Permian Liangshan Formation quartz sandstone, sandstone, shale with coal seam.

Table 5. Statistics of rock consisting of quart minerals

Stratum	Rock formation	Tunnel mileage	Length/m	Distance/m
Permian Liangshan Formation	Quartz sandstone, sandstone, shale with coal seam	DK162+180~ DK162+275	95	8400
Lower section of Jiusi Section of Datang Stage of Lower Carboniferous System	Argillaceous limestone with shale, Carbonaceous shale, sandstone	DK164+678~ DK168+513	3835	2160~6000
Permian Liangshan Formation	Quartz sandstone, sandstone, shale with coal seam	DK170+030~ DK170+070	40	600

The surrounding rock of the three sections is located in front of the working face of the water and mud inrush part of the outlet. The quartz sandstone, sandstone and shale of the Permian Liangshan Formation are the closest to the coal seam, which is the parent rock of the filling medium. The analysis is as follows: The overall terrain of the tunnel site is high in the northeast direction and low in the southwest direction. Therefore, the groundwater system generally flows in the southwest direction, and the tunnel line is 6 °-41 ° in the northwest direction, and the intersection angle with the regional tectonic line is 37 °-73 °. In addition, the stratum through which the tunnel passes is alternately distributed between the soluble rock stratum and the non-soluble rock stratum. Due to the water-blocking characteristics of the non-soluble rock stratum, it is difficult to form a southeast-flowing groundwater system. Therefore, it is less

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likely that the filling medium is carried to the water and mud inrush point after weathering by the first two sections of surrounding rock.

According to the analysis results of the mineral composition of the filling medium, it can be seen that the filling medium is carried by the movement of the underground river, and the parent rock of the filling medium is the quartz sandstone, sandstone and shale of the Liangshan Formation. The groundwater source direction is northeast.

4.4. Hydrogeological conditions and determination of groundwater source of water and mud inrush

According to the plane distribution map of Laxiang groundwater system in Libo County (see figure 12), it can be seen that the groundwater system flows through the Dongliu-vegetable garden (from northeast to southwest). After reaching the vegetable garden, it flows to the southeast and enters the Laxiang area in the form of surface water system, and finally flows into the Zhangjiang River. The tunnel crosses the groundwater flow of the tunnel willow-vegetable garden and intersects near PDK170 + 671. The source of water inrush comes from the groundwater system. According to the mineral analysis results of the filling medium, it is inferred that there is a hydraulic connection between the groundwater system and the Lazhai-mercury-Layu water system in the northeast direction of Dongliu.

Therefore, it can be seen that the source of large-scale water inrush in tunnel PDK170 + 671 is underground river water. The underground river is developed from the surface water system in the water wave area into the contact zone between the limestone of the Middle Permian Maokou Formation (P_2m) and the limestone of the Lower Permian Qixia Formation (P_2q). The underground river flows from the northeast to the southwest, exposes the surface in the Laxiang area, and forms the surface water system into the Zhangjiang River.

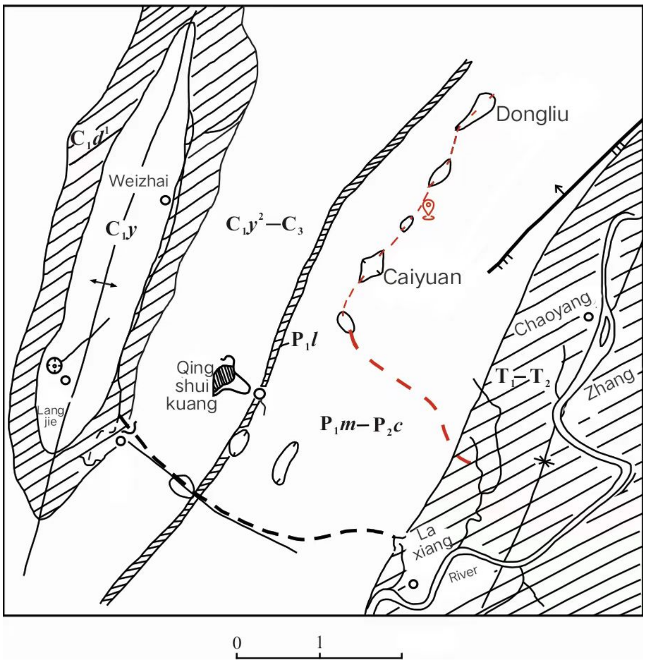

Figure 12. Plane distribution of Laxiang ground water system

5. CAUSE ANALYSIS OF INTERMITTENT WATER AND MUD INRUSH IN TUNNEL

The tunnel PDK170 + 671 water and mud inrush disaster-causing system belongs to the karst cave type, and is connected with the underground river to increase the risk of the karst cave

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type disaster-causing system. The disaster-causing system is a large karst system developed under the comprehensive action of formation lithology, rock occurrence, topography, groundwater circulation and so on.

First of all, the karst cave is at the junction of thick-thick layered limestone. The limestone of Maokou Formation is very favorable for karst development, and the shale is non-soluble rock. In the contact zone between soluble rock and non-soluble rock, large karst cave cavities, underground rivers and other karst systems are easily developed. In terms of topography, there is a karst depression above the boundary of the stratum, with an area of about 900,000 m^3. The large area of negative terrain on the surface is conducive to the collection of surface water, and constantly infiltrates to recharge groundwater, promotes groundwater flow, and then promotes the development of karst caves. In the occurrence of rock strata, the dip angle of this section is 40-50°, and the surface recharge area is large, which is very conducive to the infiltration of groundwater along the layer and promotes the development of deep karst. The overall terrain of the tunnel site is high in the northeast and low in the southwest. The trend is N35-45E. The groundwater flows in the soluble rock layer and flows to SW. Therefore, large groundwater systems, such as underground rivers, are easily developed inside soluble rock formations. It can be seen that the vicinity of PDK170 + 671 is a section where large karst caves are easily developed, and the probability of encountering karst caves during tunnel excavation is large.

The main geological reason for water and mud inrush in tunnel construction is that the tunnel construction encounters karst caves (the dissolution cracks exposed by excavation and connected with karst caves). Rich surface rainfall is another important reason. Libo County enters the rainy season from late April every year, and the rainfall gradually increases. The rainfall from March to May accounts for about 30 % of the year, and the monthly rainfall from June to August reaches more than 2 000 mm, accounting for about 50 % of the year. In May 2018, the rainfall in Libo County reached 250.4 mm, which was larger than that in previous years. On June 4,2018, the rainfall was 53.6 mm, which reached the rainstorm standard. The surface heavy rainfall infiltrates the groundwater, which increases the water pressure in the cave and increases the risk of water and mud inrush.

Through the analysis of the filling medium and hydrogeology in the karst cave, it is inferred that the underground river may be developed in the stratum where the water and mud burst in the tunnel, and there is a southwest flow along the P1 m soluble rock stratum, and the groundwater connection is more extensive. According to the water level data of Yudanshan Reservoir 1000 m northeast of the tunnel, the water level of the tunnel PDK170 + 671 decreased on the same day after the water and mud burst, and the water level decreased to one fifth of the original at 11: 00 the next day. It shows that there is a hydraulic connection between the reservoir and the karst cave of water and mud inrush point. After a large amount of karst cave and underground river water is discharged, the reservoir water level drops due to the infiltration of the reservoir water into the underground recharge karst water system.

In summary, the geological conditions of the PDK170 + 671 water and mud inrush section of the tunnel are very favorable for the development of karst caves. The water source of water inrush comes from the water in the karst cave, underground river water and surface rainfall. There is a recharge relationship between the Yudanshan reservoir and the groundwater system where the water and mud inrush location is located.

6. CONCLUSIONS

The process of intermittent water and mud inrush in Chaoyang tunnel was systematically analyzed, and the particle gradation, roundness, mineral composition of filling medium and hydrogeological conditions in Chaoyang tunnel were analyzed. The causes of karst cave development and intermittent water and mud inrush are revealed from the aspects of stratum

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lithology, topography, rock dip angle, surface rainfall and groundwater source. The major conclusions are as follows:

(1) The particle gradation curve of the filling medium is gravel type, and the failure mode of the first water and mud inrush in the tunnel belongs to the seepage instability type.

(2) The particle roundness of filling medium is good, and the main content of mineral composition is quartz. There is a hydraulic connection between the revealed karst cave and the underground river.

(3) The karst cave water, the underground river and the surface rainfall are the main sources of water inrush. There is a recharge relationship between the Yudanshan reservoir and the groundwater system where the water inrush and mud inrush are located.

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REFERENCES

[1] Wang Mengshu. Development of railway, tunnel and underground space in China [J].Tunnel construction, 2010,30 (04); p. 20-25.

[2] Li Shucai, Wang Kang, Li Liping ,et al. Formation mechanism and development trend of water inrush disaster in karst tunnel [J].Journal of Mechanics, 2017,49 (01); p. 30-35.

[3] Huang Xin. Disaster-causing system of water and mud inrush in tunnel and disaster mechanism of intermittent water and mud inrush in filling karst cave[D].Shandong University, 2019. p. 84-89.

[4] Xian Guo, Shi Shaoshuai, Zhao Yong, et al. Research and Application of Comprehensive Prevention and Control Method for Water Inrush in Water Enriched Under-Crossing River Tunnel[J].Hazard Control in Tunnelling and Underground Engineering, 2019,1(2): p. 74-82.

[5] How shiny. Geological disasters and disaster-causing structures in tunnel construction and their disaster-causing modes [J].Modern tunnel technology, 2019, 56 (S1) : p. 83-85.

[6] Chen Dejin. Analysis of causes of water and mud gushing in Anshi Tunnel and research on collaborative treatment technology[J] Geotechnical Foundation, 2021,35 (03) : p. 21-26.

[7] Zhang Xin. Study on safety distance and water inrush risk assessment between water conveyance tunnel and concealed karst cave [D].Guilin University of Technology, 2023.DOI : p. 10-15.

[8] Zhang Minqing, Wang Gang, Sun Guoqing. Treatment Technology of Mud Burst Disaster in Baiyun Tunnel of Nanguang Railway [J]. Journal of Railway Engineering, 2012,29 (03) : p. 69-73.

[9] Yuan Yongcai, Li Shucai, Li Liping, et al. Comprehensive analysis of water and mud inrush associated disaster sources in Shangjiawan strong karst tunnel [J].Journal of Central South University (Natural Science Edition), 2017,48 (01) : p. 55-68.

[10] Wu Peirong. Mechanism analysis of water and mud inrush and rotary jet grouting technology in deep water-rich steeply inclined weak zone of Liangshan tunnel [J].Tunnel construction, 2015,35 (04) : p. 68-70.

[11] Zhang Minqing, Peng Feng, Zou Mingbo, et al. Treatment technology and engineering application of water and mud inrush in unfavorable geology of railway tunnel[J].Railway Engineering Journal, 2013 (09) : 65-71. p. 65-74.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202402_10(2).0002

[12] Zhou Yi. Mechanism, prediction, early warning and engineering application of water inrush in tunnel filling pipeline structure [D]].Shandong University, 2016. p. 50-62.

[13] Liu Jinquan, Yang Diansen, Chen Weizhong, et al. Study on the starting velocity of particles in the expansion of water inrush channel of fully weathered granite [J].Geotechnical mechanics, 2017,38 (04); p. 102-104.

[14] Li Yan, Jin Zhenkui, Jin Ting, et al. Study on geological significance of roundness of magmatic rock gravel[J].According to the Journal of Sedimentology, 2014, 32 (02). p. 63.