Calculation and Analysis of Water Inflow in Huangyan Tunnel Construction

Minghao Ye [a], Haijun Sun [b]

College of Resources and Environment, Henan Polytechnic University, Jiaozuo 454003, China

[a]1553144206@qq.com, [b]1536422094@qq.com

Abstract

Accurately predicting the amount of water inrush from tunnel construction has always been a difficult point in tunnel construction at home and abroad. There is no mature method at present.Taking the Huangyan tunnel project as the background, three different methods are used to calculate the water inflow capacity of the tunnel construction, and the analysis and evaluation are carried out according to the calculation results, which provides geological basis for tunnel design and construction.

Keywords

Tunnel, water inflow,calculation and analysis.

1. Project Overview

The Huangyan Tunnel runs along the northwest. The northwest of the tunnel starts from Yangcun Village, Huangyan Township, Huaihua City, and ends in Shuiwei Village, Anjiang Town, Hongjiang City. The imported mileage is DK17+828, the export mileage is DK34+858, the length is 17030m, and the tunnel has a maximum buried depth of 700m. It is a single-hole double-line tunnel. There are five inclined shafts in the tunnel: Tangjiawuchang inclined shaft is 660m, Ganzishan inclined shaft is 2149m, Meiziniang raking shaft is 2686m, Lishuiwan inclined shaft is 1208m, and Changxikeng inclined shaft is 636m.

2. Overview of geological conditions

2.1 Formation lithology

The survey area is widely distributed in the Paleozoic Banxi formation and the Sinian metamorphic slate. The Carboniferous thick layered dolomite and dolomitic limestone develop in the syncline core. The new to old exposed ground layer is as follows:

2.1.1 Quaternary

Q4dl＋el:It is mainly distributed in mountain slopes and gentle valleys. The lithology is clay, silty clay, etc. Brownish yellow to brownish gray, 0.5~3m thick, hard plastic.

2.1.2 Carboniferous

Zhangshuwan Formation（Czs）

Ashstone sandstone, silty shale, with a thickness of 0~53.5m.

Dabu Formation（Cd）

White thick layer of dolomitic limestone and gray-white dolomite with a thickness of 496.8m.

2.1.3 Cambrian

The lower part of the lithology of the Cambrian Niutitang formation (∈n) is gray-black to medium-sized siliceous rocks with siliceous slate and carbonaceous slate. The upper middle grayish black to medium-sized carbonaceous slate contains a small amount of dark gray thin layered siliceous rock with eye-shaped and ellipsoidal phosphorus nodules. Radioactive elements such as uranium and vanadium are present in this layer, which is the key layer of this radioactive investigation. The thickness of the area is 201.1m.

2.1.4 Sinian

Fulu ~ Datangpo formation (Zf-d) middle and lower metamorphic pebbly sandstone, gravel silt slate, sericite slate, upper gravel silt slate, sericite slate, regional thickness 118.4 m.

The middle and lower part of the Qunhongjiang formation (Zh) metamorphic pebbly sandstone, pebbly siltstone containing gravel silt slate, sericite slate, upper gravel silt slate, calcareous slate superficial metamorphic boulder The sandstone contains pebbly siltstone and sericite slate with a thickness of 1137m.

The lower part of the Jinjiadong formation (Zj) is mud-like crystalline dolomite, mudstone, argillaceous limestone with carbonaceous slate, and the upper part is calcareous slate, siliceous slate with siliceous rocks and slate. The thickness of the area is 67.5~77.5m.

The Liuchapo formation (Zl) siliceous rocks, argillaceous siliceous rocks, carbonaceous slate, siliceous slate, slate, with a thickness of 48.4~91.1m.

2.2 Geological structure

2.2.1 Fold

The tunnel mainly crosses the Huangyan synclinorium.The synclinorium is composed of the Huangyan syncline, the Sanjiaotang anticline and the Baimadong syncline. The pleats are mostly gentle and wide sloping pleats, the superimposed interference is obvious, and the secondary pleats of the complex pleats develop. The pleat deformation mechanism is curved fold. The axis of the Huangyan complex slant is near NE, and the plane is "S"-shaped. The latest stratum of the trough is the Upper Zhangshuwan Formation of the Carboniferous system. It is longer than 10km and the axial surface is developed. It is a composite superimposed fold for Caledon and Indosinian. The axis of Baimadong syncline is NE50°. Curved spread on the plane, raised to the sides, the latest stratum of the trough is the upper Dabu formation of the Carboniferous System. The inclination angle is 20° and it is relatively gentle. The axial surface is developed and it is the Indosinian fold about 5km.

2.2.2 Fault

The fracture structure of the tunnel penetration area is very versatile, and can be roughly divided into NEE fault, NNE fault and NW fault according to the distribution direction and combination form of the fracture. According to the main properties of the fracture, it can be divided into positive slip fracture, reverse fracture, and slip and translation fracture. The tunnel crossing area is based on positive slippage and fracture. The strike is NE to NNE and the tendency is SE or NW, inclination is 50-70°. Use strong rock wrinkles, tensile breccia, silicified zone, cataclasite belt, lenticles and striation as a symbol of construction. The main fractures are:

Tuanposhan-Zhupozhai fracture, Miepo fracture, Heiedong fracture, Langzhu fracture, Bengtu-Huangtuqiao fracture, Jingangtian-Yanao fracture and translational fault.

2.2.3 Joint fissure

The joints and fissures of the Huangyan tunnel area are relatively developed. According to the statistics after this survey. The main trends are 95°, 135°, 205° and 296°. The joint length of the joint crack varies from 0.5 to 3m. The minimum spacing is 0.1m and the maximum spacing is 0.5m. The joint fissures mostly extend in a straight line, the crack surface is mostly straight, the part is curved (wavy), the closed-micro-form is mainly, and the part is open and filled with mud.

3. Hydrogeological conditions

3.1 Hydrogeological features

3.1.1 Type of groundwater

According to the aquifer geotechnical category, rock combination relationship, groundwater occurrence conditions and hydrodynamic characteristics, the investigation area can be divided into four types: loose layer rock soil pore water, bedrock fissure water, structural fissure water and karst water. The level of erosion of groundwater is H1, and the level of carbonization environment is T2, which is described as follows:

1)Loose layer rock soil pore water

It is mainly distributed in the residual layer of the top of the mountain to the semi-slope and the alluvial layer and the alluvial layer of the mountain valley. It mainly receives atmospheric precipitation replenishment, high terrain, rapid excretion, small amount of water, and is obviously affected by the season.

2)Bedrock fissure water

The bedrock fissure water is mainly rich in bedrock in the joints and fissures of low mountains and hilly areas. Generally, the metamorphic rock zone is not rich in water.

3)Structural fissure water

The structural fissure water mainly depends on atmospheric precipitation, upper mountain surface water, and adjacent bedrock fissure water replenishment. The turbulent conditions are related to the nature and scale of the fault structure, and the surface is discharged to the surface water system at the low-lying area, or connected to the surface water system.

4)Carbonate karst water

Carbonate-like karst water is distributed in limestone, dolomitic limestone and argillaceous limestone karst development belts. It is rich in water, and is subjected to atmospheric precipitation, Quaternary pore submerged vertical recharge and lateral recharge of bedrock fissure water. It is mostly excreted in the form of spring water on the surface.

3.1.2 Groundwater recharge

The entrance and exit area of the tunnel is steep and steep, and it is a metamorphic rock area. The surface water runoff is rapid, the precipitation has rapid runoff along the surface, and the amount of water infiltrated into the ground is limited. The surface precipitation mainly flows along the surface of the mountain in the form of scattered water, and is discharged to the low and low places around the mountain by means of scattered water. It is also collected in the surface water system of the gully and low-lying area. In the local structure of the tunnel and the development of the fracture, part of the surface water infiltrates along the fault or fissure to form tectonic fissure water, which is mostly excreted in the form of concealed descending spring.

The middle part of the tunnel is a karst area of Huangyan, which is distributed in the Huangyan depression and the white horse depression. The surface water and groundwater collected by the Huangyan depression will pass through the surface river and flow into the lion's mouth cave (768m) in the Tianjia Village, and flow out from the black chicken cave (level 622m, measured flow rate is 288.96l/s), and then remitted to the surface river Longyan River (500m elevation). The groundwater collected by Baimatun is converged to the Baimadong dark river exit (up to 750m) through a variety of pipelines and discharged into the surface river Helijiang (elevation 580m).

The elevation of the lowest drainage datum of the Huangyan karst area is about 500m. The tunnel is buried about 300m deep and is located in the non-soluble rock stratum below the deep karst water circulation zone, with structural fissure water or bedrock fissure water as the main structure. The dip structure of the limbs rock formation is relatively slow, the rock mass fissures are separated by heavy and heavy rock layers, and the penetration to the deep is inhibited, and it is generally difficult to have through-flowing gap water. The clastic rock is mostly muddy and is a good aquifer. Therefore, there are not many deep fissure waters, and there is less possibility of water inrush from high-pressure fissures. Large-scale fault zones may have through-fractures due to the fracture of the rock mass, and the possibility of high-pressure fracture water in the deep tunnel is not excluded.

4. Tunnel water inflow forecast

According to the understanding and comprehensive analysis of geological conditions, the calculation of the water inflow in Longnan tunnel mainly uses three methods[1]:

1 precipitation infiltration method[2];2 groundwater dynamics method[3];
3 underground runoff modulus method[4];

4.1 Atmospheric precipitation infiltration coefficient method (water balance method)

The amount of water in the tunnel varies greatly depending on the season. Therefore, when predicting the amount of water in the tunnel, the normal water inflow and the maximum influx in the rainy season should be calculated separately. The correctness of water inflow prediction depends mainly on the correct analysis of the tunnel water filling conditions and the reasonable selection of calculation parameters and calculation methods.The calculation method is as follows:

$Q=1000*A*X*a$

Q: The amount of water in the tunnel passing through the water body (m^3/d), the maximum water inflow is 1.5 times the normal water inflow.

A: Tunnel catchment area

α: precipitation infiltration coefficient

X: precipitation weighted average daily rainfall

(The average daily rainfall of average annual rainfall is 12mm when calculating normal water inflow)

The estimated amount of water inflow is shown in Table 1.

Table 1 Fractional water inflow estimate

Position		Length	α	X（mm）	A	Qnormal	q0	Qmax	q0max	Surround rock water content partition	Remark
DK17+828	DK18+040	212	0.01	12	0.14	16.8	0.08	25.2	0.12	few water area	
DK18+040	DK18+240	200	0.2	12	0.2	480	2.4	720	3.6	Mid water rich area	F1
DK18+240	DK19+730	1490	0.01	12	2.89	346.8	0.23	520.2	0.35	Weak water rich area	
DK19+730	DK19+900	170	0.2	12	0.22	528	3.11	792	4.66	Mid water rich area	F2
DK19+900	DK22+225	2325	0.01	12	6.05	726	0.31	1089	0.47	Weak water rich area	
DK22+225	DK22+780	555	0.3	12	1.1	3960	7.14	5940	10.7	Strong water rich area	F3~F4
DK22+780	DK23+850	1070	0.01	12	2.16	259.2	0.24	388.8	0.36	Weak water rich area	
DK23+850	DK24+330	480	0.4	12	1.76	8448	17.6	12672	26.4	Strong water rich area	F5~F6
DK24+330	DK25+600	1270	0.05	12	2.42	1452	1.14	2178	1.71	Mid water rich area	
DK25+600	DK26+050	450	0.4	12	1.39	6672	14.83	10008	22.24	Strong water rich area	F7~F8

DK26+050	DK27+445	1395	0.01	12	2.7	324	0.23	486	0.35	Weak water rich area	
DK27+445	DK27+760	315	0.4	12	1.45	6960	22.1	10440	33.14	Strong water rich area	F9

Position		Length	α	X（mm）	A	Qnormal	q0	Qmax	q0max	Surround rock water content partition	Remark
DK27+760	DK28+265	505	0.01	12	1.2	144	0.29	216	0.43	Weak water rich area	
DK28+265	DK28+720	455	0.2	12	1.21	2904	6.38	4356	9.57	Strong water rich area	F10
DK28+720	DK29+180	460	0.01	12	1.15	138	0.3	207	0.45	Weak water rich area	
DK29+180	DK29+430	250	0.2	12	0.45	1080	4.32	1620	6.48	Mid water rich area	F11
DK29+430	DK30+460	1030	0.01	12	2.1	252	0.24	378	0.37	Weak water rich area	
DK30+460	DK30+770	310	0.4	12	0.41	1968	6.35	2952	9.52	Strong water rich area	F12
DK30+770	DK31+070	300	0.01	12	0.75	90	0.3	135	0.45	Weak water rich area	
DK31+070	DK31+235	165	0.2	12	0.2	480	2.91	720	4.36	Mid water rich area	F13
DK31+235	DK32+725	1490	0.01	12	1.56	187.2	0.13	280.8	0.19	Weak water rich area	
DK32+725	DK32+935	210	0.3	12	0.85	3060	14.57	4590	21.86	Strong water rich area	F14
DK32+935	DK33+350	415	0.01	12	1.13	135.6	0.33	203.4	0.49	Weak water rich area	
DK33+350	DK33+670	320	0.2	12	0.2	480	1.5	720	2.25	Mid water rich area	F15
DK33+670	DK34+858	1188	0.01	12	1.16	139.2	0.12	208.8	0.18	Weak water rich area	
	Total	17030				41231		61846			

4.2 Groundwater dynamics method

According to tunnel water inrush boundary conditions and deep hole pumping test results, groundwater dynamics method is used to calculate the water inflow of tunnel (DK24+330~DK25+600). The calculation method is as follows:

$Q=B*K*(2H-S)*S/2*R$

Q: The amount of water in the tunnel passing through the water body (m^3/d)

K: aquifer permeability coefficient (m/d)

H: aquifer thickness (m)

S: Water level drop depth (m)

B: length of the tunnel through the aquifer (m)

R: radius of influence of tunnel water inrush (m)

The thickness of the aquifer is obtained by substituting the relevant data into the above formula to obtain $Q=341m^3/d$, and the maximum water inflow of the tunnel unit length $q0max=0.27m^3/d.m$.

4.3 Underground runoff modulus method

Karst weakly developed tunnels and non-karst rock tunnels (rock fissure water), calculated by the following formula.

(1)Calculate the normal water inflow of the tunnel(Q_s)

$$Q_S = M_y \cdot A \approx 2.70 M_d \cdot A$$

Q_s-Normal water inflow through tunnels in water-bearing areas(m^3/d)

M_y-Annual average underground runoff modulus($m^3/(d\bullet km^2)$)

M_d-Dry season underground runoff modulus($m^3/(d\bullet km^2)$)

A-The catchment area of the tunnel through the water body section(km^2)

(2) Calculate the maximum water inflow of the tunnel(Q_{max})

$$Q_{max} = \lambda \cdot M_y \cdot A \approx 1.50 Q_s$$

Q_{max}-The maximum amount of water in the tunnel passing through the water body(m^3/d),About 1.5 times the normal water inflow of the tunnel;

λ—coefficient of modulus:

$$\lambda = \frac{\text{Maximum rainfall}}{\text{Average annual rainfall}}$$

According to the relevant statistical results, the modulus ratio is recommended to be 1.5.

According to the 1:20W Xupu geogeological area report, the average underground runoff modulus in the dry season is $45.792 m^3/d \cdot km^2$.

The calculation results are as follows:

$Q_s = 2.7 \times 45.792 \times 31.87 = 3940.4 m^3/d$

$Q_{max} = 1.5 \times 3940.4 = 5910.5 m^3/d$

In summary, use the groundwater dynamics method to calculate the water inflow from the tunnel, the results are greatly affected by the boundary conditions of the tunnel water and the hydrogeological characteristics of the aquifer. Due to the complex geological conditions of the tunnel, the tectonic development and the stratigraphic differences are large, using groundwater dynamic method to predict the tunnel water inflow will have a big error. The underground runoff modulus prediction method is used to calculate the tunnel water inflow, and it is impossible to consider different sections of the tunnel. In particular, the difference in water inrush in the fault zone cannot be based on the calculated amount of water inflow. Therefore, the underground runoff modulus method is also not suitable for predicting the amount of water in the tunnel. Comprehensive comparison, the use of atmospheric precipitation infiltration coefficient method to predict the amount of water in the tunnel.

4.4 Analysis of water inflow

Calculations proves that:

DK18+040~DK18+240(F1 fault fracture zone),

DK19+730~DK19+900(F2),

DK24+330~DK25+600,

DK29+180~DK29+430(F11),

DK31+070~DK31+235(F13),

DK33+350~DK33+670(F15) tunnel areas are medium water-rich areas，

while the

DK22+225~DK22+780(F3~F4),

DK23+850~DK24+330(F5~F6),

DK25+600~DK26+050(F7~F8),

DK27+445~DK27+760(F9),

DK28+265~DK28+720(F10),

DK30+460~DK30+770(F12),

DK32+725+DK32+935(F14) are strong water-rich areas. And others are all weak water-rich areas. There is a high possibility of water inrush in these areas, and advanced geological prediction should be strengthened in design and construction. The tunnel has passed 15 breaks, near the fault and its influence zone, the surrounding rock of the cave is mostly broken, and the mechanical properties and overall stability of the rock and soil are poor;Meanwhile, the fault development area is easy to become a water guiding channel, and the groundwater is introduced into the tunnel body, causing water inrush, mud and landslides, strengthening support and drainage measures are required during construction.

The water inrush and muddy phenomenon of the Huangyan tunnel is mainly concentrated in the fault zone, the limestone and metamorphic rock contact zone and the white horse syncline axis section. There are many fractures in the tunnel area, the rock in the fault zone is strongly broken, the structure is loose, the water is rich, and the water content is large, which is a good water guiding channel. The saturated water deteriorates the geotechnical state in the fault zone and the stability deteriorates. When the tunnel is built through the fracture zone and the white horse to the oblique axis, it is easy to cause water inrush and mud, which threatens the safety of people and machinery.

5. Conclusion

When the tunnel crosses the fault zone, it destroys the original complementary balance and compensation conditions of groundwater and surface water, forming a penetrating groundwater collection corridor, which causes the groundwater to change the original turbulence direction and collect it into the tunnel, resulting in the loss or even depletion of surface water. It has an impact on the lives of local residents.

Comprehensive analysis shows that the geological structure of the tunnel is developed, the local rock mass is broken, and the localized bedrock dissolution and fissures develop, which provides favorable conditions for groundwater enrichment. According to the lithology of the stratum in the tunnel area, the geological structure, the degree of water-rich partitioning of the surrounding rock, and the predicted water inflow, the hydrogeological conditions of the tunnel are poor.

References

[1] Ren Zengzeng. Calculation and Analysis of Water Inflow in Longnan Tunnel Construction[J]. Water Resources Science and Technology, 2018, 24(10): 22-25.

[2] Zhu Dali, Li Qiufeng. Prediction of tunnel water inflow using empirical value of precipitation infiltration coefficient[J]. Journal of Railway Engineering Society, 1995(1): 100-102.

[3] Zhu Dali, Li Qiufeng. Method for predicting water inflow from tunnels[J]. Engineering Investigation, 2000(4): 18-22, 32.

[4] Mao Jianan, Shi Zhongping, Bi Huanjun. Comprehensive survey of hydrogeology and prediction of water inflow in Qinling tunnel[J].World Tunnel,1998(2):44-48.

[5] Li Pengfei, Zhang Dingli, Zhou Wei. Research on Prediction Method and Influencing Factors of Tunnel Water Inflow[J]. Journal of Beijing Jiaotong University, 2010, 34(4): 11-15.