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Influence analysis of drainage mode on the karst tunnel lining under high water pressure

In order to avoid lining cracking caused by high water pressure deformation and damage of the disease, the lining water pressure of many domestic karst tunnels are summed up, showing that the tunnel drainage is the main factor causing the high lining water pressure. For a passenger line tunnel, the numerical calculation model of finite difference method FLAC2D is established. It analyzes the characteristics of tunnel lining water pressure under side wall corner drainage mode of ditch at "two side ditch + center ditch", pointing out that the invert arch pressure is huge and the lining safety is low under the condition of high pressure and rich water and drainage mode of "two side ditch + center ditch". In order to improve the safety and reduce the water pressure, the drainage sheme of the drainage ditch under the inverted arch is proposed and the water pressure of the tunnel lining is calculated and analyzed. The analysis shows that the drainage ditch can effectively reduce the water pressure of the inverted arch, which can improve the safety of the tunnel structure through the drainage ditch under the invert of the high pressure water rich karst tunnel.

Keywords: *Karst Tunnel; tunnel drainage; tunnel lining water pressure; drainage ditch under invert arch.*

1. Introduction

With the rapid development of China's transportation infrastructure construction, an increasing number of mountain tunnel construction are in Karst area. Not only in the karst tunnel construction where sudden gushing mud mass may occur, which brought great difficulties to the construction and operation period of karst tunnel due to the effect of karst high pressure, cracking, lining deformation, arch destruction disease also occur [1-3]. Therefore, it is necessary to carry out the research on the safety of lining structure and lining structure of the karst tunnel in the operation period. High lining pressure karst tunnel is mainly under water pressure, and the factors that affect the water pressure of the tunnel lining are the geological conditions of the tunnel and the drainage way of the tunnel. Tunnel drainage is divided into three categories: the whole row, the whole block and water blocking, limited drainage. "Full drainage" can greatly reduce the role of water pressure on the lining, but no drainage will cause serious damage to the ecological environment. The water plugging adopts tunnel grouting, grouting circle formed tight around the tunnel to reduce the permeability of surrounding rock, thus reducing the emissions of groundwater, which however did not reduce the water pressure on lining; "emission limit" penetrates into the water in the grouting circle through the lining and lining two between the water drainage system (horizontal and vertical blind pipe, vent pipes, drains) discharge so as to reduce the role in the two lining external water pressure. Therefore, the reasonable drainage system and drainage system is the key to ensure the normal operation of karst tunnel. Currently, the domestic scholars have more studies on the external water pressure of high water pressure in karst tunnel lining. For Zhang Youtian [4] the lining water pressure reduction coefficient is expressed as the product of three factor, namely considering the correction coefficient of correction coefficient, the initial groundwater seepage field under different surrounding rock and lining permeability and considering the correction coefficient of drainage the role of the system. Meanwhile, it puts forward the values of the parameters in different geological conditions; Wang Jianyu [5] based on the simplified axial symmetry derivation of isotropic and homogeneous medium under steady flow behind the lining of the pore water pressure and seepage force in the liner range, and the seepage force lining within the scope of the force of the value of pore water pressure on the lining is calculated; Li Pengfei [6] researched change of initial support, two lining and grouting circle parameters such as the reduction of water pressure reduction system; Ren Yao spectrum [7] relied on the West Qinling Mountains tunnel, by FLAC3D simulation to analyze the underground water level, the permeability coefficient of surrounding rock, ring spacing, thus blinding pipe grouting circle permeability, grouting circle thickness and displacement of lining water pressure influence. In a large number of research literature,

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Table 1: Several karst tunnel drainage pattern and lining water pressure

Tunnel name	Drainage pattern	Lining water pressure	Remarks
Xiangfan Chongqing railway tunnel in Liangshan [8]	Full drainage	Close to 0	After the tunnel surface water depletion, ground subsidence, serious damage to the environment
The Hengyang Guangzhou railway Dayaoshan tunnel [8]		Close to 0	
Chuanqian line Loushanguan tunnel [8]		Close to 0	
Jinshazhou tunnel of Wuhan Guangzhou Passenger Dedicated Line	Full water blocking	Arch water pressure is small, inverted arch water pressure is huge	Lining water pressure is large, the local water seepage phenomenon occurs during the operation of the tunnel, which affects the normal operation of the tunnel
2# cavity section of Liangshan tunnel [9]		Vault lining water pressure reached 2Mpa	
Xiangpu Road Daiyunshan tunnel [10]	Water plugging limit	The water outlet pressure is small, the vault and invert water pressure	The drainage way of water blocking and drainage is effective to reduce the water pressure of tunnel lining
Liangshan tunnel in Chongqing No.1 traffic line [11]		The actual water pressure is much less than the design value of water pressure	

the influence of drainage mode of tunnel and drainage system on the safety of lining structure is quite less. This paper lists many domestic drainage tunnel and the lining water pressure, it is pointed out that the better drainage mode is limited drainage .This paper established a calculate mode on “two side ditch + center ditch” drainage with FLAC2D finite difference method, analysis pointed out that the tunnel is low when drainage on “two side ditch + center ditch” methord. Puts forward drainage ditch under invert arch and analyzes the rationality and superiority of this drainage scheme.

2. Example analysis of water pressure in different drainage methods

It can be seen from the Table 1: the water pressure of lining water is almost 0, but the environmental impact is great. When the tunnel is completely blocked, the lining structure can bear large water pressure. If the water level is high, the lining water pressure is very large, which may cause the lining leakage or the lining crack. The “grouting + drainage” Limiting row design, grouting circle bears a part of water pressure and reduces the effect of water pressure on the lining lining water pressure relative to the underground water level reduced, which is more close to the drainage hole, the lining water pressure is small; the vault and invert lining is in hydraulic force. In general, the depth of the 60m as a “critical head closure”, only when the groundwater level is below the critical value, it is reasonable to take the full closure waterproof [5], when tunnel depth is more than 60m by blocking water, seeking to limit discharge drainage pattern.

3. Stress analysis on lining structure of “water blocking limit drainage” of high water pressure karst tunnel

Currently, high pressure and rich water karst tunnel mostly adopts water plugging and limiting discharge drainage and binding mode, in order to study the limiting behavior of lining structure under the mode of discharge force based on a passenger line tunnel project, this paper selects typical section Syncline area, establishes the FLAC2D finite difference numerical model and analyzes the stress characteristics of lining structure under the mode of “two side ditch + center trench”.

3.1 Introduction of tunnel project

Some bus line got developed through the limestone and dolomite karst, the lower Triassic breccia, the karst strongly developed. The total tunnel length is 6861m, the maximum depth is about 750m, most of the depth of the buried depth is 200 ~ 300m, the design speed is 250km/h.

Selecting the tunnel syncline segment as calculation section to establish two-dimensional model. This section is mainly the V-grade surrounding rock, limestone and dolomite with karst breccia. The tunnel is in the excavation contour line outside the 5m in advance of the surrounding grouting, the tunnel adopts bilateral ditch plus center ditch drainage.

3.2 Numerical model and parameter selection

The calculation model takes 8 times the diameter of the model from the side wall of the tunnel excavation to the two sides, with a total size of 240m. Taking 80m from the roof, which is about 6.5 times higher than the hole; taking about 5 times the height of the hole from the bottom of the tunnel; with a total of 160m. The buried depth section is 230m, the underground water level line under the surface line is 30m. The calculation model is shown in Figs.1 and 2. The calculation parameters are shown in Table 2.

The bottom boundary displacement and the horizontal displacement of the left and the right boundary of the model are constrained; the self-weight stress and hydrostatic

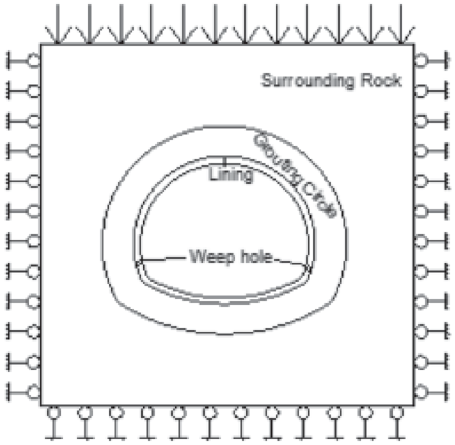

Fig.1 The model of "two side ditch+ center ditch"

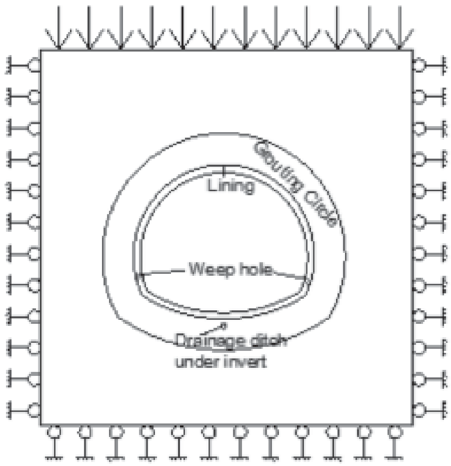

Fig.2 The model of drainage under the inverted arch

pressure of the upper rock mass are applied to the top of the tunnel. The bottom of the tunnel is the impermeable boundary, the left and right boundary pore water pressure is fixed [12-16].

3.3 Numerical results analysis

3.3.1 Analysis of water pressure on the lining of "two side ditch + center ditch"

The lining water pressure distribution is shown in Figure 3, the lining water pressure is less than the hydrostatic pressure, which because the drainage hole drainage reduces the effect of water pressure on the lining as far away from the drainage holes because of the vault and invert water pressure.

3.3.2 Analysis of internal force of the lining of "two side ditch + center ditch"

Based on the vertical stress and horizontal stress of the numerical calculation, the normal stress of the inner and outer edge of the critical section is calculated, and the axial force and bending moment of the key section of the lining structure are calculated. The calculation results are shown in Figs.4 and 5.

Based on results from Figure 4 and Figure 5, internal force of lining structure are under pressure, vault and invert parts of pressure, bending moment and the corner parts of large arch waist bears larger pressure. The maximum axial force is in the vault and the maximum bending moment is at the foot of wall.

3.3.3 Safety evaluation of lining structure

According to the design parameters of tunnel, the safety factor of lining structure is calculated by the method of damage phase specified in the code for design of railway

Table 2: The numerical calculation parameter

Material	Density (kg/m^3)	Elastic modulus (GPa)	Poisson ratio	Internal friction angle (°)	Cohesion (MPa)	Porosity	Permeability coefficient (cm/s)
Surrounding rock	2350	1.5	0.4	35	0.5	0.2	1×10^{-4}
Groutig circle	2400	1.95	0.35	40	0.55	0.15	2×10^{-6}
Lining	2500	35	0.2	-	-	0.1	1×10^{-10}
Drain hole	2500	35	0.2	-	-	0.5	5.23×10^{-2}

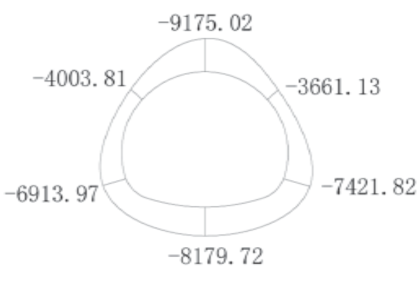

Fig.3 Water pressure of "two sides ditch + center ditch" (unit: MPa)

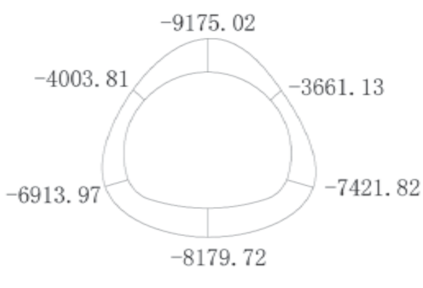

Fig.4 Axial force of "two side ditch + center ditch" (unit: kN)

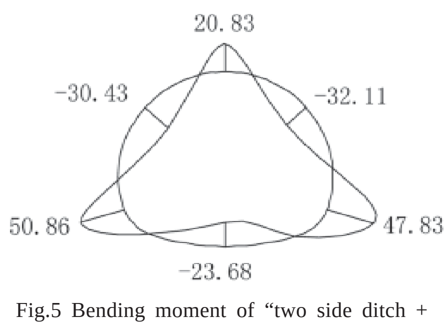

Fig.5 Bending moment of "two side ditch + center ditch" (unit: kN, m)

Fig.6 Safety factor of “two side ditch + center ditch”

Fig.7 Drainage ditch under invert

tunnel [17], and the safety factor of lining structure is shown in Fig.6.

According to the railway tunnel design code, the strength safety factor of the reinforced concrete structure should not be less than 2.0.

The results show that the safety factor is small and the safety factor of the arch waist and side wall is larger. The safety factor of each part of the tunnel lining is greater than 2.0 and the safety of lining structure meets the requirements of the standard.

4. Force analysis of tunnel lining structure on the condition of drainage ditch under inverted arch

The actual statistic data of numerical simulation results show that the "two side ditch + center ditch" caused the inverted arch invert water pressure, minimum safety coefficient. In recent years, the emergence of disease cases about the tunnel in operation is increasing due to withstanding high water pressure. Based on this kind of situation, it puts forward the drainage scheme of drainage ditch under the invert, as shown in Fig.7.

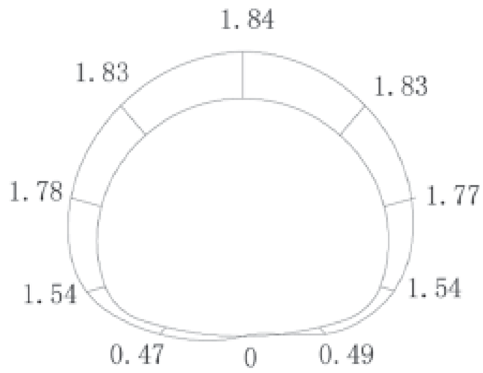

Fig.8 Water pressure of Invert drainage (unit: MPa)

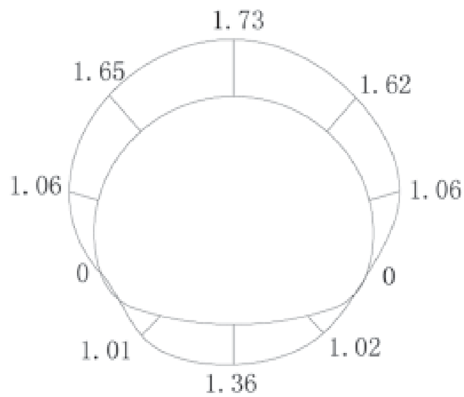

Fig.9 Water pressure of wall drainage (unit: MPa)

4.1 Force analysis of lining structure of drainage ditch under invert arch

The two dimensional model of the inverted arch is established by the two dimensional model for fluid solid coupling calculation. The tunnel section and the parameters are the same as the 3.2 section. The numerical calculation model is shown in Fig.2.

4.2 Comparison of calculation results

4.2.1 Results contrast of drainage under inverted arch and drainage in the wall corner

Two drainage ways lining water pressure distribution is shown in Figs.8 and 9. As be seen from Figure 8: drainage under inverted arch can greatly reduce the inverted arch water pressure. It can be seen from the figure 9 that corner drainage can greatly reduce the lining water pressure at the corner. when far away from the corner ,the inverted arch lining water pressure is higher. For high water pressure karst tunnel, inverted arch is often the weak part of the lining, drainage under inverted arch can reduce the water pressure of inverted arch, which can effectively improve the safety of lining.

For two drainage ways, the lining structure internal force distribution is shown in Figs. 10, 11, 12 and 13. We can see that lining structure are both under pressure, but compared with the corner drainage ,the invert drainage is strong safety and less pressure, only the axial force increases slightly.

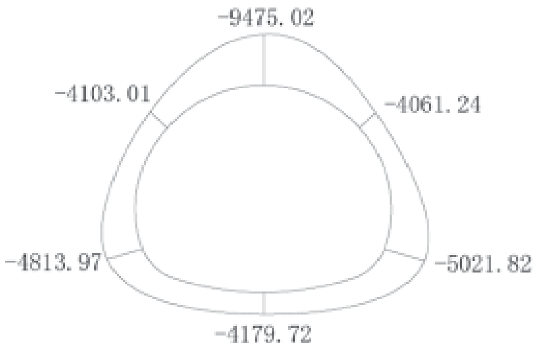

Fig.10 The axial force of invert drainage (unit: kN)

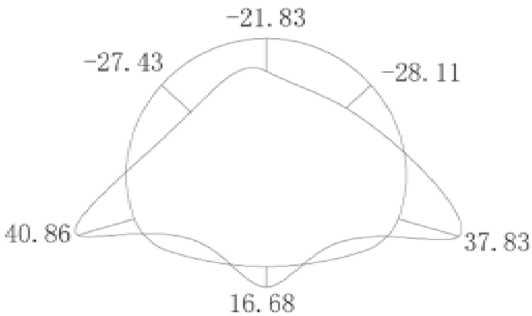

Fig.11 The bending moment of invert drainage (unit: kN)

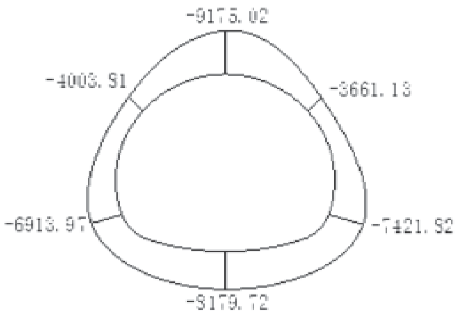

Fig.12 The axial force of wall drainage (unit: kN)

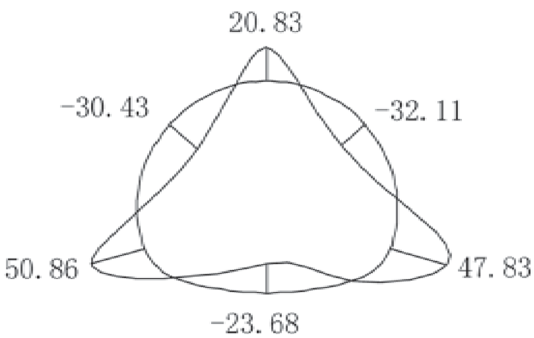

Fig.13 The bending moment of wall drainage (unit: kN m)

4.2.2 Structure safety contrast for two drainage way

Two drainage ways lining safety coefficient comparison is as shown in Figure 14 and 15: for invert drainage, safety factor is higher than wall drainage, only the top arch, which

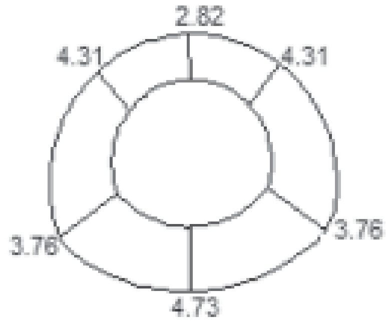

Fig.14 Invert drainage lining safety coefficient

Fig.15 Wall drainage lining coefficient

is slightly lower. Compared with the corner drainage, the inverted drainage can improve the stress state of lining structure and improve the safety factor of the lining structure.

5. Summary

(1) In addition to tunnel geological conditions, factors affecting the external water pressure include karst tunnel lining and tunnel drainage, tunnel plugging water, lining structure under high water pressure. If the underground water level is very high, then the lining water pressure large, which may cause cracking or lining lining seepage Water Leakage.

(2) When the water is limited drainage, the water pressure will be reduced to the ground water level. Tunnel side wall drainage, drainage holes near the lining water pressure is the minimum. The inverted arch and vault lining water pressure is large, the safety factor is the minimum, the invert is a weak part of side wall drainage lining structure.

(3) Drainage under the inverted arch can reduce the water pressure of the inverted arch lining, which can reduce the internal force of the inverted arch and optimize the stress of the lining structure, thus improving the safety factor of the lining structure. Groundwater rich, water pressure areas are advised to adopt the “inverted drainage” model.

Acknowledgment

National Natural Science Foundation of China (Project No. 51678226); Hunan science and technology project

(2014SK3180); research key project of Hunan Provincial Education Department (15A035)

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