Study of the cracking mechanism of the secondary lining of Jijiawan tunnel

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Abstract

The cracking of the secondary lining of tunnel is a common seen phenomenon but the cause can be complex due to its dependence on the local environment. In this work, we have analyzed the cause of the cracking mechanism of the secondary lining of Jijiawan tunnel. Through the study of the geological and engineering background of Jijiawan tunnel, the field investigation and analysis of the secondary lining cracking, the collection of second lining cracking monitoring data and field drilling test experiments, we conclude that the secondary lining crack is caused by the slope sliding induced by the construction of the tunnel, where the slope sliding force is greater than the secondary lining bearing capacity. To further analyze the cause of cracking, we established a simplified mechanical model by numerical simulation. The dynamics analysis further confirmed the cause to be the slope slip. Our results provide valuable reference for related tunnel lining cracking.

Keywords

Tunnel; secondary lining cracking; cracking mechanism.

1. Introduction

With the rapid development of transportation, in recent years, various tunnels have been built in China. For the tunnel constructed by the new Austrian method, the structural form is mainly the initial support of the anchor spray support, and the composite lining structure with the moulded concrete as the secondary lining permanent lining.The secondary lining cracking of the tunnel is a common phenomenon in tunnel construction. The crack that tends to be stable after cracking is regarded as a stable crack, and the crack that keeps developing after cracking is regarded as a dangerous crack, and it is necessary to find the cause for timely treatment in order to avoid the occurrence of disasters such as collapse and secondary lining damage.

Scholars at home and abroad have carried out studies on the second liner cracking of tunnels. Asakura and Kojima[1]describe the deformation mechanism of the lining;SuSheng[2] have studied the cracking mechanism and crack resistance highway tunnels; ChenZhenhe[3]used the principle of fracture mechanics to study the mechanism of tunnel second lining cracking;WangRuifeng[4] used Ansys simulation to optimize the design of the two-liner structure of the multi-arch tunnel;ZhangYongxing and YangJunsheng[5]analyzed the cause of the cracking of the second lining of a shallow-buried double-arch tunnel, which shows that firstly excavating the tunnel on the inner side of the mountain is beneficial to prevent cracking of the second lining;ZhangLiancheng and YanXiaobo[6] analyzed the slippage of the shallow tunnel and the cracking of the lining, which indicated that the slope of the tunnel entrance caused the cracking of the second lining of the tunnel;ChenZuhui and ChenTielong[7] explained the causes of the cracks in the tunnel second lining

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concrete from the aspects of non-standard construction process or on-site operation, poor quality of raw materials and unreasonable design of the mix ratio, and proposed corresponding treatment measures;LiuXuezeng and GuYincheng[8] used the finite element numerical simulation method to analyze the tunnel lining cracking process under external force, and obtained the process and sequence of tunnel crack cracking. From the literature on the study of tunnel second lining cracking at present, the mechanism of tunnel second lining cracking under the joint action of rock joint and topographic bias is less considered. However, in the tunnel construction, such a tunnel appears. Therefore, Its research is necessary.

Jijiawan tunnel is a separate tunnel from Gucheng to Zhuxi Expressway. After the the construction completed, cracking occurred. The author determined that the secondary lining crack was an external load through the investigation of the site cracking and the drilling experiment. caused. According to the cracking of the upper mountain part of the tunnel, the numerical simulation experiment and the deformation monitoring data of the on-site vault, it can be seen that the second lining crack of the tunnel is caused by the sliding of the upper slope.

1.1 Jijiawan tunnel engineering overview

The tunnel of Jijiawan is located in Malan Village, Hongta Township, Fang County, Shiyan City, Hubei Province. The tunnel is located in Malan Village, Hongta Township, Fang County, Shiyan City, Hubei Province. The direction of the tunnel axis is about 264°, which is distributed in the east-west direction. The ground elevation of the tunnel crossing section is 381.6~529.0m.The left-length Mileage pile number is ZK84+975~ZK85+670, the total length is 695m, the maximum buried depth is about 123.1m; the right-length mileage pile number is YK84+975~YK85+655, the total length is 680m, and the maximum buried depth is about 128.1m. It is a separate tunnel. The exposed and exposed strata in the tunnel area are mainly the Quaternary Holocene residual slope (Q4el+dl) silty clay and the Silurian Meiziyu Formation (S1m) schist. The surface water system in the tunnel area is not developed, mainly the surface flow formed by atmospheric precipitation and the seasonal flowing water in the mountain valley.

The open hole construction adopts the open cut method, and the dark hole V-level surrounding rock section: the left hole is excavated by the short-step left core method, and the right hole is excavated by the middle partition wall method, where the left hole is first excavated, and the right hole is followed up; Class IV surrounding rock section: Separate tunnel adopts upper and lower step excavation method, and small clearance tunnel adopts short step to retain core soil method for excavation, first excavation left hole, right hole follow-up; III-level surrounding rock section : Excavation by the step method. Finally, the tunnel is compounded with a lining.

2. Secondary lining cracking of tunnel

2.1 Site investigation

On April 18, 2013, the research team conducted a site investigation on the secondary lining cracking of the Jiajiawan tunnel.The crack section is ZK84+975~ZK85+285（Cracks began to appear after one year of secondary lining support）.The surrounding rock grade is Grade IV, the portal section is Grade V, and the second liner support type is reinforced concrete. A sketch of the typical section (ZK85+086~ZK85+131) is shown in Figure 1. In this section, 9 cracks are visible, which extend obliquely from the side wall to the vault. The crack 6 and the crack 8, the crack 7 and the crack 9 have a tendency to communicate, and become a bamboo crack.

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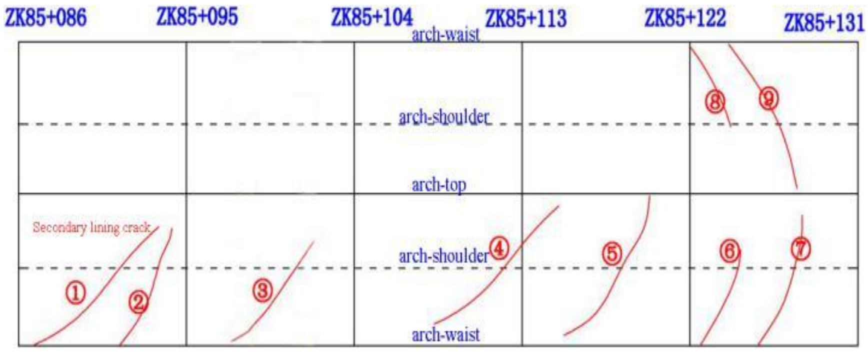

Figure 1. Schematic of tunnel lining cracking expansion based on site record

The field statistics of cracks 1~9 are shown in Table 1. The width of the cracks is more than 5mm, and all need to be treated, and the development length of the cracks is also 4~10m, and the estimated depth is more than 5cm. Among them, the cracks 5 to 9 have a development trend.

Table1. expansion plan cracks characteristics statistics

Crack marking	Width（m）	Length（m）	Estimated depth	Whether there is a trend
①	0.006	8~9	0.06	no
②	0.007	6~7	0.07	no
③	0.006	6~7	0.06	no
④	0.005	6~8	0.05	no
⑤	0.006	8~10	0.06	yes
⑥	0.005	6	0.05	yes
⑦	0.008	8	0.08	yes
⑧	0.006	4	0.06	yes
⑨	0.009	8	0.09	yes

Photograph of crack ⑨ is shown in Figure 2below.

It can be seen from the photograph that the crack extends obliquely to the vault and a small amount of groundwater seeps out from the crack, indicating that the crack has partially penetrated.

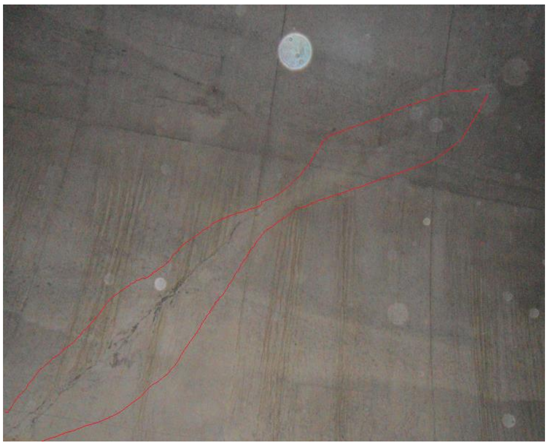

Figure 2. cracks pet-name ruby photos

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2.2 Analysis of secondary lining cracking monitoring data

The construction unit monitors the cracks with development trend when the cracks are found. The monitoring trend of the cracks 9 is shown in the figure below. It can be seen from the figure that the crack width growth in the first 6 months is small, whereas the cracks in the later 6 months increased obviously. According to the investigation at the scene, the mountain above the tunnel was cracked at 6 months, and with the arrival of the rainy season, the cracks in the mountain were widened, which greatly affected the widening of the second liner crack.

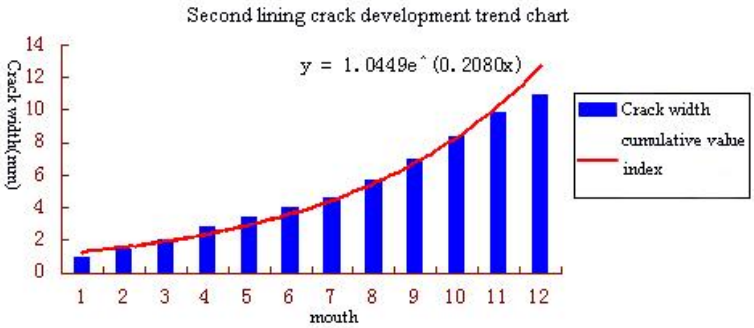

Figure 3. the width of crack pet-name ruby along with the development of the time

3. Analysis of the causes of cracking of the second liner

3.1 Drilling test

The reason for the cracking of the tunnel liner is that the load on the structure (lining) exceeds its own load carrying capacity. There are three main reasons for the cracking of the second liner: one is that the two liner structure itself can not withstand excessive load; the second is that after the second liner structure is complete, the surrounding rock pressure exceeds the capacity of the second liner to cause cracking; the third is for water leakage and cracks are caused by freezing damage.

Figure 4. second lining crack drilling position

In the analysis of the cause of the second liner cracking, the cracks caused by water leakage and freezing damage are first excluded, because the tunnel does not have these problems (in the territory of Hubei Province, there is no frost damage; and there is no water leakage when the second liner is applied). The main consideration is the integrity of the secondary liner structure. Based on this, several holes were drilled near the second liner to verify the integrity of the second liner structure, as shown in Figure 4. From the field test, it can be known that the second liner structure is complete and conforms to the size of the design. Therefore, the external load is mainly considered for the cause of the tunnel second liner crack.

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3.2 Analysis of the causes of the second liner cracking

According to the local situation of the tunnel, as wel as the scene of the investigation in the previous section, there are cracks in the bamboo cutting type, indicating that the upper part of the tunnel is subjected to the oblique force; the cracks extend from the side wall to the vault, indicating that the crack side wall is firstly subjected to the concentrated force from the external load making the bearing capacity to be unable to resist the surface force of the external load and breaks; the crack has a development trend, indicating that the stress concentration part continuously moves toward the vault; the crack has a penetration tendency, and the entire second lining is destroyed, which needs to be strengthened. Measures; the mountain above the tunnel is cracked, indicating that the mountain is cracked by the downward tension. In summary, it can be known that the secondary lining cracking of the tunnel is caused by the sliding of the stable slope during the tunnel construction, which causes the bearing capacity of the tunnel two lining structure to be less than the sliding force. See Figure 5 below for illustration.

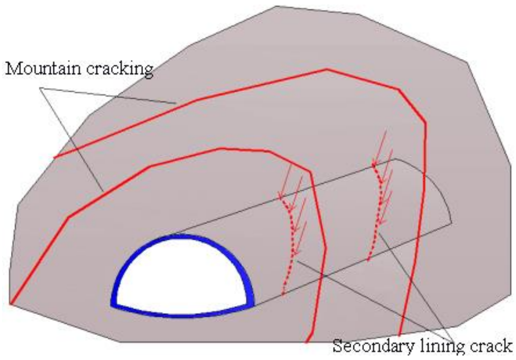

Figure 5. the slope body caused by cracking

4. Analysis of mechanical mechanism of tunnel second lining cracking

4.1 Model establishment

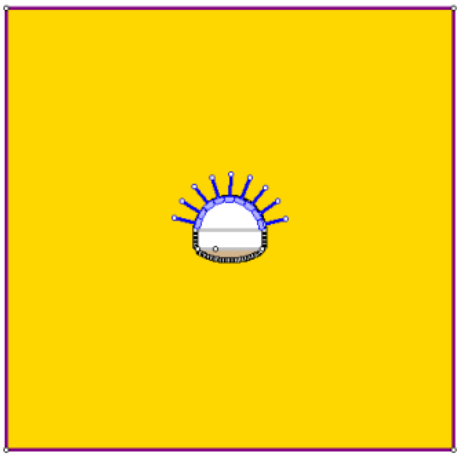
Figure 6. tunnel model

The typical section ZK85+124 of the tunnel entrance section is selected. The minimum depth of the section is about 70m. The plane strain model of Figure 6 is established. For the convenience of modeling and research, the bamboo-cutting and two-line cracking are simplified. The rectangular shape and the original tunnel [9], the length of the model selected in the analysis is 108m in the horizontal direction and 56m in the vertical direction, and the self-heavy stress of 46m is applied to the top. A horizontal displacement constraint is applied to both sides of the model, and a vertical constraint is applied to the bottom.

The phase 2 is used for simulation, and the surrounding rock is elastoplastic material, which satisfies the Mohr-Coulumb yield criterion [10]. The beam element is used to simulate the initial lining and

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the second lining, and the rod unit simulates the anchor. The surrounding rock parameters and support parameters are shown in Table 2 and Table 3 above.

Table 3. tunnel lining supporting parameters

Elastic Modulus	Poisson's ratio	unit weight	Cohesion	Internal friction/
GPa		(kN m-3)	MPa	(0)
4	0.32	22	0.25	53

Table 2. Grade V SLATE physical parameters

Support method	Elastic Modulus	unit weight	Cross-sectional area	Moment of inertia/(0)
	GPa	(kN m-3)	MPa	
System anchor	210.0	78	0.00038	--
Initial lining	25.0	23	0.10000	--
Second lining	30.0	27	0.3000	0.00225

The first support is used for excavation, which is in line with the actual situation of the site, and the main condition of the second lining is observed.

4.2 Calculation results

It can be seen from the axial force diagram of the second lining of Fig. 7. Under the gravity of the upper rock mass of the second lining, the arch is mainly subjected to compressive stress, and the arch is mainly subjected to compressive stress, and the maximum shear stress is also At the arch. The second lining is rigidly supported, and the compressive stress is not subjected to tensile stress. Therefore, excessive stress is applied to the arch and the side wall, and cracking occurs first. Since the rock schist in the upper part of the arch is soft rock, creep occurs, making the arch The cracking of the foot continuously extends up to the vault until it penetrates, and the entire two-lining structure is destroyed.

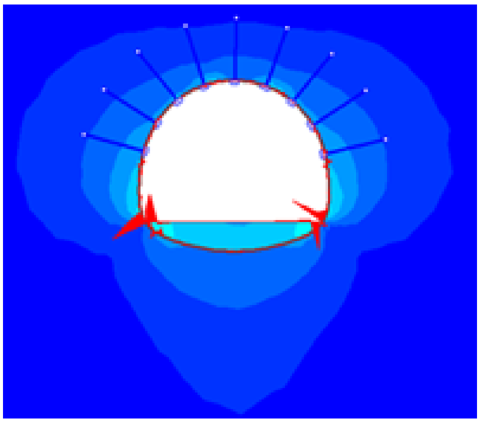

Figure 7. Shear stress diagram

4.3 Tunnel displacement-time monitoring data

According to the above qualitative and simulation studies, it can be seen that the tunnel vault sinks when the slope is slid. This can also be proved according to the field data. See Figure 8. Displacement time of the ZK85+115~ZK85+130 section. Curve, as seen from the figure, the sinking of the vault still has a development trend.

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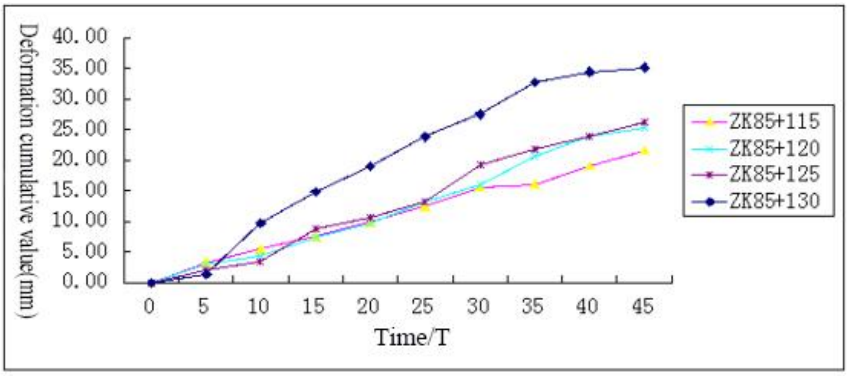

Fig.8 vault time - displacement curve

5. Conclusion and suggestion

5.1 Conclusion

(1)According to the on-site investigation, the second lining cracking of the Jiajiawan tunnel has certain regularity, and its extension extends from the side wall to the vault, and it is a bamboo-cutting distribution (longitudinal extension, spanning multiple modes), which has significantly different characteristics from the general two-line cracking. And through the on-site monitoring data of the second liner cracking, it can be seen that most crackings have a growing trend.

(2)Through the on-site drilling experiment, the reason for the cracking of the second liner is attributed to the external load. According to the characteristics of the crack and the cracking characteristics of the upper part of the tunnel, the cause of the cracking of the second lining is attributed to the upper slope is slid, which exceeds the bearing capacity of the second lining to cause structural damage.

(3)According to the above investigations, a numerical simulation model is established. The calculation shows that the tunnel vault is under a pressing force, the side wall is subjected to a large pulling force, and the second lining is pressed but not pulled, resulting in the side wall damage firstly. The occurrence of damage, continuous oblique extension and the result of on-site cracking, can be confirmed according to the field vault displacement monitoring data.

5.2 Suggestion

Such cracking in the tunnel should be treated timely. The treatment of the cracking can be divided into the outside and inside parts of the cave. . The treatment of outside the cave includes two aspects. One is the back pressure backfill at the foot of the slope (completed during the monitoring period), and the other is to re-maintain the slope drainage system to prevent the rain from further scouring the slope. There are also two treatment measures inside the cave. One is to demolish and dismantle the second lining blocks and re-cast it. The second is to grout the backing of the second lining with holes.

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