

Analysis on Progressive Failure Process of Immersed Surrounding Rock of Large-section Loess Tunnel

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Abstract

The Baishi No.2 tunnel project of Lanzhou-Zhongwei railway as the background, the influence of rainfall and groundwater on the tunnel in Lanzhou area is discussed. The reasons for the deterioration of surrounding rock immersion in 15 tunnels at home and abroad are counted, and the reasons for the deterioration of surrounding rock immersion in loess tunnels are summarized and analyzed, and suggestions are given. The results show that the collapse of the surrounding rock of the soaking deteriorated loess is sudden, and the high incidence position is the tunnel vault, but the surrounding rock will undergo large deformation before the collapse until the surrounding rock is destroyed. After the collapse of the surrounding rock of the water-immersed deteriorated loess, multiple collapses will occur in a short period of time. These collapses do not meet the law of large deformation first and then collapse, and there are almost no signs. Therefore, the reinforcement of the water-immersed deteriorated loess should be focused on before the first collapse ; in the construction of shallow buried tunnel with soaked and deteriorated surrounding rock, the influence range affects the surface. The possible overload condition on the surface should be controlled to prevent the occurrence of surface overload from accelerating the early deformation process of surrounding rock and causing the collapse of surrounding rock.

Keywords

Surrounding Rock Immersion; Loess Tunnel; Progressive Failure Process; Large Cross-Section.

1. Introduction

From western Ireland in the west to eastern China in the east, the loess strata connect the whole Eurasian continent [1]. Under the background of the " Belt and Road " economic development strategy, the planning of railway network in Northwest China is becoming more and more perfect, and the number of loess tunnels is gradually increasing. Loess is a Quaternary sediment, which often exists in the surface of sedimentary rocks and is a typical water-sensitive geological body [2]. Rainfall [3], irrigation infiltration [4, 5], leakage [6], groundwater [7] and flood [8] will have an impact on the surrounding rock of the loess tunnel. After the loess is immersed in water, the connection key between the internal particles is sharply weakened, the weight is increased and the shear strength is decreased, which leads to a significant decrease in the resistance to the sliding of the surrounding rock, and induces a large number of loess tunnel disasters, such as the collapse of the tunnel face, the collapse of the unsupported area of the vault and the collapse of the back-closed door. The safety of the construction personnel and the safety of the tunnel structure during operation cannot be guaranteed.

2. Rainfall Survey in Lanzhou Area

The loess in Lanzhou area of China has strong collapsible characteristics. In order to study the degree of loess affected by water in Lanzhou area, the total rainfall from July to September in Lanzhou area in the past 20 years was investigated. As shown in figure 1, it can be concluded that the rainfall in the rainy season of 2017, 2018 and 2020 exceeded 250 mm, and such rainfall was mainly concentrated on one of the days. Compared with other rainfall-rich areas, Lanzhou area is more likely to be affected by indirect rainstorms, such as Lanzhou rainstorm event in April 2018, Shaanxi, Gansu, Ningxia and flood disasters in May 2024. Baishi No.2 Tunnel of Zhonglan Railway is located near Baishitougou, Xiuchuan New Village, Qilihe District, Lanzhou City. The maximum buried depth of the tunnel is about 24 m. At the exit section, it is a shallow-buried large-section loess tunnel. The surface is farmland, and the terrain is low. It is easily affected by surface rainfall and groundwater, resulting in a significant deterioration of the strength of the surrounding rock of the loess tunnel and a series of geological disasters in the tunnel, which seriously affects the safety of tunnel construction and operation. The stability of surrounding rock during construction is an important issue facing the safety of tunnel engineering. Therefore, it is of great theoretical significance and engineering application value to study the disaster evolution process and stability of large section loess tunnel construction under the condition of surrounding rock immersion deterioration.

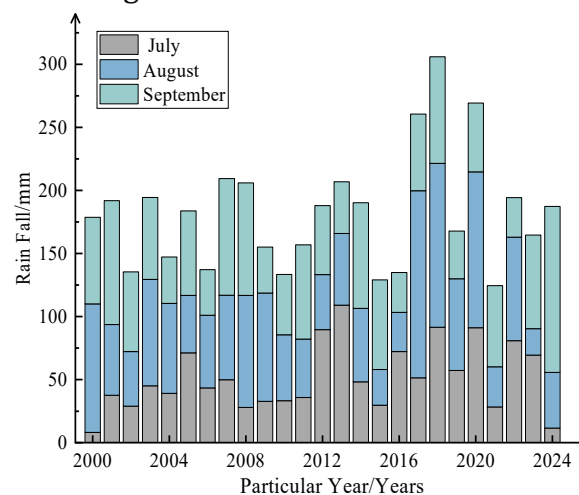


Figure 1. Rainfall investigation of rainy season in Lanzhou area in recent 20 years

3. Statistical Analysis of Immersed Tunnel

The disaster statistics of 15 immersed tunnels at home and abroad are shown in Table 1. It can be concluded that most of the tunnels are immersed in groundwater. In water-poor areas, the main source of groundwater is rainfall, so Lanzhou and other places should pay special attention to the influence of rainfall on surrounding rock.

4. Conclusion

The collapse of surrounding rock of loess immersed in water is sudden, and the high incidence position is the tunnel vault. However, before the collapse, the surrounding rock will undergo large deformation until the surrounding rock is destroyed. In order to prevent the damage of the tunnel vault, the deformation of the surrounding rock of the tunnel vault should be reduced as much as possible during the excavation of the tunnel. After the excavation, the steel arch frame is quickly constructed, and the steel arch frame is locked to reduce the deformation of the vault. The locking foot is only a temporary construction strategy, and the large section tunnel should be ringed early.

Table 1. Statistical Analysis of 15 Immersed Tunnels

Numbler	Tunnel name	Types and characteristics of loess	Causes of tunnel instability
1	Yulinzi Tunnel [9]	Quaternary Upper Pleistocene Malan loess, Middle Pleistocene Lishi loess with multi-layer paleosol	groundwater
2	Shanggecun Tunnel [10, 11, 12]	The Quaternary upper Pleistocene and middle Pleistocene aeolian clay loess with water content of 13 % ~ 32 %.	rainfall
3	Shangzhuang Tunnel[13]	The water content of sandy loess in the upper Pleistocene of the Quaternary, clay loess in the middle Pleistocene of the Quaternary and mudstone in the upper Pleistocene of the Tertiary is 25.7 % ~ 32.1 %.	water-rich
4	Yima No.1 Tunnel [14, 15, 16]	The surface layer is permeable Malan loess ; the lower layer is Lishi loess. The moisture content is 26.4 % ~ 33.4 %.	Groundwater, rainfall
5	Lanzhou rail transit line 1 [17]	Artificial fill, alluvial loess soil, pebbles and sandstone. Moisture content 28.5 %	The cause of seepage is unknown
6	Qiaoyuan Tunnel [18]	Quaternary upper Pleistocene aeolian deposits, Quaternary middle Pleistocene alluvial deposits.	groundwater
7	Zhangmao Tunnel [19]	Quaternary Middle Pleistocene clayey loess, natural moisture content of 23 %	groundwater
8	Erzhuangke Tunnel [20]	Quaternary Malan loess, Lishi loess	rainfall
9	Jingyou Tunnel [21]	Expansive loess layer	Rainfall, surface water
10	Lexing Tunnel [22]	The Quaternary upper Pleistocene Malan loess and middle Pleistocene loess and multi-layer paleosol with water content of 25.7 % ~ 27 %.	groundwater
11	Zhaojiashan Tunnel [23]	loess	Rainfall, groundwater
12	Xi 'an subway Tonghuamen-Hujiamiao interval [24]	Saturated soft soil, ancient loess.	Rainfall, groundwater
13	Zhaojiagou Tunnel[25]	loess	Rainfall, groundwater
14	Fanjiawo Tunnel [26]	malan loess	the Yellow River water infiltration
15	Bailuyuan Tunnel [27]	Lishi loess, Malan loess and mudstone	groundwater

After the collapse of the surrounding rock of the water-immersed deteriorated loess, multiple collapses will occur in a short period of time. These collapses do not meet the law of first large deformation and then collapse, and there are almost no signs. Therefore, the reinforcement of the water-immersed deteriorated loess should be focused on before the first collapse. If the collapse damage has occurred during the construction process, the construction personnel should be quickly withdrawn. After multiple collapses are stable, safer construction methods should be adopted, such as advanced pipe shed grouting to strengthen the surrounding rock of the vault.

In the construction of shallow buried tunnel with soaked and deteriorated surrounding rock, the influence range affects the surface. The possible overload condition on the surface should be controlled to prevent the occurrence of surface overload from accelerating the early deformation process of surrounding rock and causing the collapse of surrounding rock.

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