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Experimental study on thermal performance of the tunnel with active heating system in cold region

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Abstract. In the cold region, the seasonal freezing and thawing for the pore water in the rock or the soil are very likely to occur repeatedly. Engineering practices show that: in the service period, more than 80% of the tunnels have different degrees of frost damage. Hence, the frost-resisting problem must be taken into account. In this paper, the Jinzhangzi tunnel was chosen as a target project and a serious of the thermal tests were carried out. Experimental result the proposed heating system can suppress occurence of the frost damage for the target tunnel.

Introduction

For a practical engineering, the load reason may cause the concrete structure to produce load cracks or environment effect. Once the pore water in the surrounding rock and soil enter into the cracks of tunnel lining, it may be frozen into the ice under the low temperature in winter, and the cracks are enlarged. Therefore, the frost prevention of tunnel in cold area is an important problem in engineering practice.

The Jinzhangzi tunnel is located in Pingquan county, Chengde city. It belongs to one part of the National Highway 101. Its very cold in winter, therefor, the frost damage may occur for the target tunnel. A new thermal protective system based on the electrical heating technology is proposed, and its effectiveness is also verified in this paper.

Engineering background

The Jinzhangzi tunnel is located near Jinzhangzi village, and its principle part run from east to west. The main surrounding rock is so-called Anshan Rock. The fracture of the rock is obvious, and the fissure water is rich. The length of the tunnel is 480m as shown in Figure 1. The primary lining adopts the C25 reinforced concrete, and its thickness is 8cm. The secondary lining is the C25 reinforced concrete, and its thickness is 30cm.

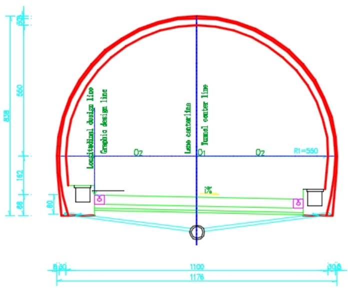


Fig. 1 Dimension of the target tunnel

The target area is very cold and snowy in winter, and the monthly lowest temperature can be far below minus 20 degree centigrade in January every year. The maximum freezing depth of the soil can reach 1.26 m below the ground surface.

Field test

Experimental device. .
In this paper, an active heating system is proposed. This system manly includes three parts, i.e. the suspension, the heating and the insulating part as shown in Fig.2.

The galvanized steel wire mesh is used for fixing the heating electrical belts. The line power of the electrical belts is 18w/m. The interval between any two branches of each heating belts is 10cm, as shown in Fig.3.The aluminum foil layer can be used for covering the heating cable area, and its thickness of aluminum foil is 0.3mm. The fluorine-free polyurethane foam can be sprayed on the surface of aluminum foil, and the spray thickness is 4cm. The key component is the temperature-controlled box, and the sensors are used for observing the temperature of the naked lining or the heated lining as shown in Fig.4.

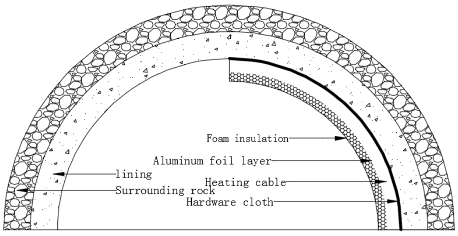


Fig. 2 schematic diagram of composite thermal insulation device

Fig. 3 In-situ heating belts

a. Temperature-controlled box b. Temperature sensors

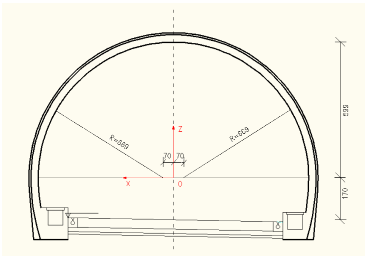
Fig. 4 Main test components

Observing scheme. In order to analyze proposed heating system, the temperature of environmental, the naked tunnel lining and the heating lining need be observed respectively.

Observing Point. Taking the point O corresponding entrance of the tunnel as origin. The horizontal direction of the entrance of the tunnel as X axis. The vertical direction of the entrance of the tunnel as X axis, coordinate system as shown in Figure 5. The test group with a span of 6m are established along the Y axis at 10m and 70m respectively, as shown in Figure 6. Every test group include tow observing point at less, one is used for observing environment temperature, and the other for observing the temperature of the lining with the heating system, corresponding to the test area, half of the surface of the tunnel is naked, and the other half is heated by the electrical belts. The first coordinate value of every observing point corresponding to the X axis. The second coordinate value of every observing point corresponding to the Y axis. The third coordinate value of every observing point corresponding to the Z axis. The distribution of observing points in each group of the tunnel lining surface as shown in Fig.7. The coordinates of each observing point are shown in the following table 1.

Table 1 The coordinates of each observing point

Test group 1		Test group 2	
Observing point	Coordinates	Observing point	Coordinates
A_t	（3.85,13, 5.9）	A_t	（-3.85,13, 5.9）
B_t	（7.33,13, 0.9）	B_t	（-7.33,13, 0.9）
D_t	（6.46,11, 3.4）	D_t	（-6.46,11, 3.4）
E_t	（6.46,13, 3.4）	E_t	（-6.46,13, 3.4）
F_t	（6.46,15, 3.4）	F_t	（-6.46,15, 3.4）
G_t	（3.85,73, 5.9）	G_e	（-3.85,73, 5.9）
H_t	（7.33,73, 0.9）	H_e	（-7.33,73, 0.9）
I_t	（6.46,71, 3.4）	I_e	（-6.46,71, 3.4）
J_t	（6.46,73, 3.4）	J_e	（-6.46,73, 3.4）
K_t	（6.46,15, 3.4）	K_e	（-6.46,15, 3.4）



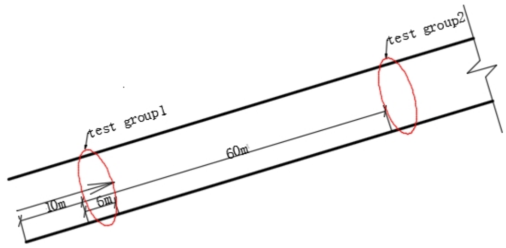
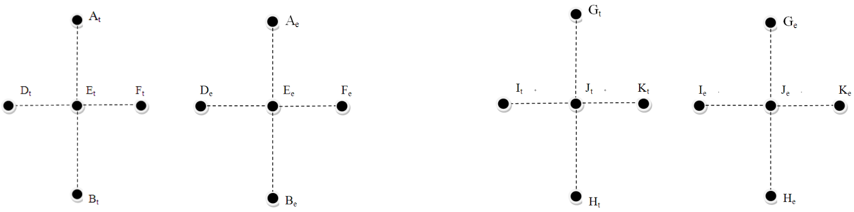
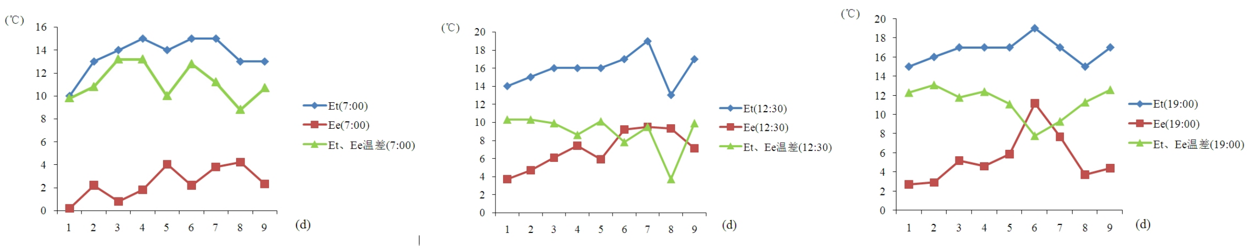


Fig.5 Control point coordinate system Fig. 6 Schematic diagram of the experimental scheme



a. Test group 1 b. Test group 2

Fig. 7 Layout of observing point



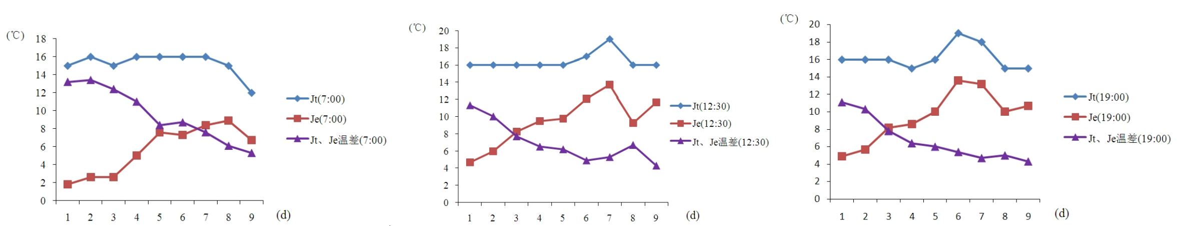
a. Et、Ee temperature comprison at 7:00 b. Et、Ee temperature comprison at 12:30 c. Et、Ee temperature comprison at 19:00

Fig.8 Temperature comparison of observing point at 13m

Considering the variation of in-situ temperature of the engineering site, the influence of geothermal energy in the tunnel, and the relationship between the sunshine and the tunnel temperature, the daily acquisition time of the observing data is set at 7:00, 12:30 and 19:00 as shown in Fig.8.

Test Analysis

Through a 9-day observation statistic, each group is drawn as shown in Fig.9. By analyzing the monitoring data of Et、Ee and Jt、Je, it's found that the proposed heating system can raise tunnel lining temperature and avoid the potential frost damages.



a. Jt、Je temperature comprison at 7:00 b. Jt、Je temperature comprison at 12:30 c. Je、Je temperature comprison at 19:00

Fig.9 Temperature comparison of observing point at 16m

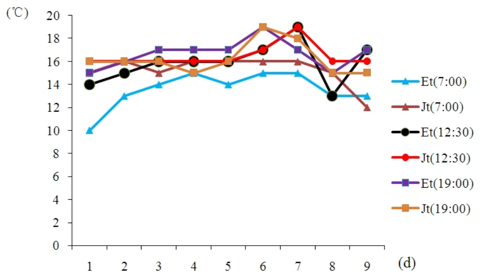


Fig.10 Comparison of temperature in test group

By analyzing the variety of temperature corresponding to the point of Ee、Je、Et、Jt, it can be seen that the ambient temperature increases with the depth of the tunnel, however, the thermal performance of heating system is stable. The environment has insignificant influence on the proposed heating system as shown in Fig.10.

Conclusions

An active heating system for thermal protection for frost damage prevention of the tunnel is applied to a practical engineering. The test results show it can solve the frost-resistive problem effectively of the tunnel, it can provide a new approach to design and construction of the tunnel in cold region.

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