Monitoring of Longitudinal Temperature Variation in Tunnel in Cold Region
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Abstract. Based on the high-altitude cold area super-long railway tunnel-Dangjinshan tunnel as the background, this paper studies the temperature distribution and its variation rule in the tunnel through the method of field measurement and theoretical analysis, and obtains the variation rule of tunnel temperature under different temperature conditions at the entrance, as well as the location of 0°C point from the entrance of the tunnel. The conclusions obtained in this paper can be applied to the study of tunnel anti-frost heaving technology and have reference value for the construction of tunnels in cold areas under similar conditions.

Introduction
With the rapid development of infrastructure construction in China, the number of tunnels in severe cold regions in traffic engineering is increasing, and tunnel diseases in cold regions are becoming more and more prominent, which has become another difficult problem concerned by the engineering community. Scholars from all over the world have systematically studied the distribution law of temperature field of tunnels in cold regions and the prevention and control technology of freezing damage, and put forward many theories and methods with practical value, which provide a basis for the anti-freezing design and construction of tunnels in cold regions. Through literature investigation [1], it is found that the main causes of many freezing damage problems encountered by tunnel engineering in cold region are insufficient understanding of the freezing damage mechanism of tunnel, insufficient understanding of the distribution law of tunnel temperature field, insufficient attention to the anti-freezing design of tunnel, and lack of experience in the rational use of anti-freezing measures. Since the beginning of the 19th century, experts at home and abroad began to study the temperature field of tunnels in cold regions. However, due to the limitations of conditions, theoretical research and laboratory experiment mainly focus on analytical solutions [2-4], and field measurement is lacking. In recent years, some researchers have carried out field measurements. For example, wang yufu studied the temperature field of the tunnel in cold region by relying on qingshashan highway tunnel project, and summarized the characteristics of the temperature change inside and outside the tunnel by testing the temperature field in the tunnel area [5]. Lai jinxing also took qingshashan tunnel as the background, through the layout of components, analyzed the structure performance and temperature field distribution of the tunnel [6]. Relying on the high altitude seasonal frozen soil tunnel, xiao xun studies the relationship between the temperature in the tunnel and the surrounding rock and the longitudinal distance by field test [7]. However, due to the influence of tunnel geographical location, engineering geological conditions, complex environment and construction technology level, there are still some problems worthy of further study. Therefore, in this paper, the Dangjinshan tunnel in the cold region of high latitude is taken as the research background, and the field monitoring method is adopted to study the longitudinal temperature variation distribution rule along the tunnel in the cold region, so as to provide guidance for the cold zone tunnel to prevent freezing damage.
Tunnel Engineering Overview

Dangjinshan tunnel is located in the Akesai Kazakh Autonomous County of Gansu Province. The entrance to the tunnel is 2,864.83m above sea level, the exit is 3107.00m above sea level, the maximum depth is 764m, the minimum buried depth is 52m, the length of the tunnel is DK194+980~DK215+120, and the length is 20.14km.

Geographic and Geomorphic Conditions

Dangjinshan tunnel is located in the middle and high mountain area of Dangjinshan. The width of north and south sides of the mountain is generally 25~35km, and the mountain width of the tunnel site area is about 28km. Due to the influence of east-west faults, the east-west fault basins in the mountains are relatively developed, and the terrain is open. The basin section is u-shaped wide valley, and the height of the valley bottom is generally 2800m~3600m. The ground elevation of the tunnel passing through area is generally between 2864m~3700m.

Hydrometeorological Conditions

The groundwater at the Dangjinshan tunnel site is dominated by bedrock fissure water, it can be divided into networked weathered bedrock fissure water and vein structure fissure water according to the cause. The tunnel is located in the cold and semi-arid climate zone, with large seasonal temperature difference, obvious rainy season and dry season, and little annual precipitation. The annual average temperature is 3.1°C, the lowest temperature is -34.3°C, and the highest temperature is 35.9°C. The average annual precipitation is 127mm, the average annual evaporation is 3297.9mm, the average temperature in the coldest month is -13.1°C, the maximum snow thickness is about 16cm, and the maximum freezing depth is 235cm.

Temperature Field Monitoring

Monitoring Content

The Dangjinshan Tunnel has a total length of 20.14km, the influence range of external atmospheric temperature on the temperature inside the tunnel is limited. It is unnecessary to monitor the longitudinal temperature inside the tunnel, so only the area with negative temperature inside the tunnel can be monitored. Therefore, the range of 2000m from the tunnel entrance is selected as the monitoring object, monitoring every 100m as an interval, in the process of the measuring length of 2000m can be divided into 20 interval, the midpoint of each interval selected as monitoring cross section, measuring the temperature value, based on direction into the tunnel and the monitoring cross section is numbered. A total of 20 monitoring cross sections are obtained. The corresponding relationship between the tunnel culling mileage and the monitoring cross section is shown in Figure 1.

![Figure 1. The corresponding relation between the length of the tunnel from beginning to end and the monitoring cross section.](image)

The change of external temperature is divided into annual change and daily change. In actual projects, the annual change of temperature is generally considered and the influence of daily change of temperature is ignored. The annual change of the temperature is the change of the monthly average temperature within a year. The monthly average temperature within a year will have the highest temperature and the lowest temperature. Because the ground will absorb some heat during the solar irradiation process, the time of the maximum value of the monthly average temperature will be delayed by 1~2 months compared with the month where the solar radiation is the strongest or weakest. The strongest and weakest months of solar radiation in China's high-altitude areas are June and December respectively, and the highest and lowest monthly average temperatures are July

26
and January respectively. The annual change of monthly average temperature can be expressed in formula (1)\(^8\).

\[
T(t) = T_m + A \cos \left( \frac{\pi}{6} (t - t_0) \right)
\]

In the formula:
- \(T(t)\) —Free air temperature, °C;
- \(T_m\) —Annual average temperature, °C;
- \(A\) —Annual variations in temperature, °C;
- \(t\) —Time, month;
- \(t_0\) —The hottest months, month.

### Analysis of Monitoring Results

**Interior Longitudinal Temperature Analysis.** From December 2016 to March 2017, the relationship between temperature and longitudinal distance in the tunnel of Dangjinshan tunnel was measured. Four groups of representative measured temperature values and the fitting curve were drawn in Figure 2.

![Figure 2. Actual temperature fitting curve.](image)

Analysis of the monitoring data and Figure 2 shows that the temperature in the tunnel gradually increases with the increase of the depth of the tunnel. At 1750m from the tunnel entrance, the temperature in the tunnel reaches above 0°C. Beyond this range, there will be no negative temperature zone behind the surrounding rocks and lining, that is no frost heaving damage occurs. At the same time, considering the existence of extreme temperature, it is appropriate to choose a range of 2000m from the tunnel for research.

**Study on the Relationship between the Temperature inside the Tunnel and the Wall Temperature.** In the process of monitoring the temperature inside the tunnel, the temperature of lining concrete surface inside the tunnel is also monitored. By comparing and analyzing the monitoring data of two groups with different monitoring time, the relationship between the temperature inside the tunnel and the surface temperature of concrete is studied, and the distribution...
law of the temperature field inside the tunnel is further understood as the theoretical basis for the subsequent research. The relationship between temperature inside the tunnel and surface temperature of lining and longitudinal distance is shown in Figure 3.

Through the analysis of the relationship between the temperature inside the tunnel and the lining surface temperature and the longitudinal distance of the tunnel in Figure 3, it can be known that:

In the morning time, the temperature in the tunnel is about 550m away from the entrance. The temperature in the tunnel is higher than the temperature on the lining surface. The temperature difference between the two is the largest at 1.5°C, with the increase of the depth of the tunnel, the temperature of both is rising, but the temperature rise of the lining surface is larger than the temperature inside the tunnel, and the distance from the tunnel entrance is 550m~2000m. The surface temperature of the lining is greater than the temperature inside the tunnel. The temperature of the local position is almost equal, which may be due to the influence of the ventilation of the transverse channel;

In the afternoon, about 350m from the entrance is the boundary point where the temperature inside the tunnel is equal to the surface temperature of the concrete. Before the hole is 350m, the temperature inside the hole is higher than the surface temperature of the lining, but the temperature difference between the two is reduced, the temperature difference at the tunnel entrance is only 0.3°C; after 350m from the tunnel entrance, the temperature inside the tunnel is lower than the surface temperature of the lining, and the temperature of both is the depth of the hole increases and increases.

The continuous increase of the solar radiation time will cause the temperature inside the hole to move in the direction of the tunnel entrance at the same point as the temperature of the lining surface. From the comparative analysis of the monitoring data 1, 2, from 10:00 am to 5:30 pm, the temperature inside the tunnel and the surface temperature of the concrete are gradually moved toward the small mileage direction by about 200m, and the temperature inside the tunnel and the surface temperature of the concrete are both increased, the temperature change at the entrance of the tunnel is the most obvious, the temperature rises by 1.6°C, and the lining surface temperature rises by 2.8°C.

**Exterior Longitudinal Temperature Analysis.** Collect and summarize the monthly average temperature of the area around the Dangjinshan tunnel site in the past 10 years by using formula (1) to carry out regression analysis of the monthly average temperature, the highest temperature month is about July of each year, then t0=7. In the preliminary fitting analysis, A= (T7-T1) /2 was taken, where T7 and T1 were the monthly average temperature in July and January respectively. The expression of annual temperature change at the entrance of Dangjinshan tunnel was shown in formula (2), and the comparative analysis of measured value and fitted value was shown in figure 4.

**Annual variation of external temperature:**
\[ T(t) = 3.69 + 16.6 \cos \left( \frac{\pi}{6} (t - 7) \right) \]  

Figure 4. The fitting curve of monthly average temperature at the mouth of the tunnel entrance

According to the analysis of the relationship between the average temperature value in figure 4 and the regression curve, formula (2) can well fit the monthly average temperature at entrance of Dangjinshan tunnel. Therefore, this function can be used as the temperature boundary condition for subsequent studies. The average monthly temperature at the entrance is below 0°C for about 5 months each year. Long-term exposure to low temperature will adversely affect the structural safety of the tunnel.

Conclusions

By monitoring the temperature and lining surface temperature of the Dangjinshan Tunnel in Dunhuang to Golmud Railway, the following main conclusions can be obtained:

1. The temperature inside the tunnel is positively correlated with the depth of the tunnel. The farther the distance from the tunnel entrance is, the higher the temperature is. The influence of the external atmospheric temperature on the temperature of the tunnel entrance is about 1750m from the tunnel entrance, and after 1750m from the tunnel entrance, the temperature inside the tunnel is positive, and there is no negative temperature zone behind the surrounding rock and lining. At the same time, considering the existence of extreme temperature, it is more appropriate to study the range of the cold insulation measures at the inlet end of the tunnel from the tunnel entrance of 2000m.

2. The temperature inside the tunnel and the surface temperature of the lining gradually increase with the increase of the depth of the tunnel, but the points with the same temperature value are dynamically changing during the day. In the morning, the point where the temperature inside the tunnel is equal to the temperature of the lining surface is about 550m from the tunnel entrance. In the afternoon, it is about 350m away from the tunnel entrance. It moves about 200m in the direction of the tunnel entrance. As the depth of the tunnel increases, the temperature inside the tunnel and the surface temperature of the lining gradually increase.

3. According to the analysis of the monthly average temperature of the outside temperature of the Dangjinshan tunnel, the formula (2) can better fit the monthly average temperature, which can be used as the temperature boundary condition for subsequent research. The entrance of the tunnel is below 0°C for about 5 months each year. The long-term low temperature environment seriously affects the safety of the tunnel during construction and operation.
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