Research on the High Ground Temperature Risk during Long Tunnel Construction

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Abstract. The high ground temperature is a prominent problem in the construction of deep buried long tunnels. Based on the analysis of high ground temperature in existing tunnels, the influence of high ground temperature on tunnel construction was divided into three situations, namely the harm to human body, effects on labor productivity and accident rate increasing. Then the high temperature heat sources during the tunnel construction were researched. The high ground temperature evolution law of famous tunnel in the history was studied by using comparative analysis method, also the reason of ground temperature anomalies and the heat transfer type of rock mass was obtained. Based on the geothermal gradient formula and the reliability theory, the risk probability model of high ground temperature was obtained in the deep buried long tunnel construction. The results show that the method can predict the high ground temperature in deep buried tunnel accurately.

Introduction

Deep buried long tunnel generally refers to the tunnel that is buried more than 400m deep and 10km long. Deep buried long tunnel in China is mainly distributed in the western mountain area, in the western region, due to the effect of intense crustal activity, hot springs and the reflective element, there is prone to high ground temperature problem. Especially in the regional active fault zone, high stress or deep buried depth tunnels(more than 1500 meters) is likely to encounter more than 35°C high temperature, also the possibility of rock creep may increase. Undoubtedly, this will increase the difficulty of ventilation and cooling during tunnel construction.

When the original temperature in tunnel reach to 28°C,it should take appropriate measures to cool down, many deep buried long tunnel meet the problem of high temperature around the world, such as the Swiss Gotthard base tunnel, which is 15km long and maximum depth is 1700m, its highest temperature is 30.7 °C. The Simplon tunnel in Switzerland and Italy, full-length is 19.8km, maximum depth is 1648m, its maximum temperature is 55.4°C, Chinese Xikang railway Qinling tunnel, full-length is 18.4km, maximum depth is 1600m, the highest temperature is 40 °C. So in the process of deep buried long tunnel construction, the problem of high ground temperature is very serious.

In this paper, the project area was located in the Tibetan plateau mutation belt, and the altitude is about 4000m, which has a complex topography, and its geological conditions are very complex. This tunnel is 73km long, the diameter of the tunnel is 12m, and the maximum depth is 1150m. The main engineering geological problems are high ground stress and rock burst, water gushing and water bursting, harmful gas, surrounding rock stability and tunnel crossing fault zone, high ground temperature, etc. Because of the lack of construction experience in area with high ground temperature and extreme hypoxia, it is very important to carry out research on the control measures in the whole TBM construction process.

Influence of high temperature to tunnel construction

With the continuous progress of tunnel construction technology, tunnels gradually become more deeper and longer than before, high temperature disease has gradually become a big problem in the tunnel engineering.

Harm to the human body. The worker are apt to get heat stroke and heat exhaustion when working in hot and humid environment for a long time, and also cause some dysfunction occurred in thermoregulation disorders, main show is an elevated body temperature and skin temperature, water and salt metabolism disorder, the body function affected. High temperature working environment make the health of workers subjected to serious harm, many people have symptoms of fatigue, shortness of breath, chest tightness, dizziness and skin eczema etc.

Effect to labor productivity and safety. In the high temperature, the average productivity is relatively low, some relative labor efficiency is only 30% ~ 40%. Based on German survey statistics, when the operating environment temperature exceeds 28°C, the accident rate will increase by 20%. According to South Africa information, when the working surface temperature exceeds the standard 1°C, the labor efficiency of the workers is reduced by 7% to 10%. According to Japan, Russia and China's high temperature mine statistics, mine working surface air temperature exceeds the standard 1°C, workers labor production efficiency will be reduced by 8% ~ 6%.

Increase of accidents rate. In hot environment, the human central nervous will be inhibited, the cerebral cortex excitatory process be decreased, conditioned reflex incubation period will be extended, attention cannot concentrate and easy to sleep, trance, fatigue, aches and weakness, groggy, and slow coordinating. It makes the work ability, control ability to drop, reaction becomes slow, there will lead to accidents. According to the survey results of seven coal mines in Japan, the accident rate increased by 1.5 to 2.3 times in the working area of 30°C to 37°C than the area below 30°C.

Geothermal analysis

Heat source analysis of deep buried tunnel TBM construction.

Heat from surrounding rock. Below the constant temperature layer, the greater the depth, the higher the rock temperature. High temperature surrounding rock heat is related to its thermal physical properties, the original rock temperature, air humidity, radiation area and surrounding rock exposure time.

Heat from the mechanical equipment and lighting equipment. At present, as the high degree mechanization of construction, heat from mechanical and electrical equipment is increasing, the driving machine is a large power machinery which will bring great difficulties to the construction.

Body heat. Under normal circumstances, one physical labor produce about 180 to 250kK heat per hour.

Statistics of temperature in deep buried tunnel at home and abroad.

Table 1 is the list of some ground temperature tunnels.

Table 1 Ground temperature tunnels at home and abroad

Country	Tunnel name	Length (km)	Maximum depth (m)	Main lithology	Temperature (°C)
Italy-France	Lyon-Torino tunnel	54.0	2000	Sand shale, limestone, quartzite,	40
Japan	Anfang highway tunnel	4.35	700	Slate, sandstone, granite diorite porphyry	75
Switzerland	Simplon tunnel	19.8	2140	Rhyolite, granite, gneiss	55.4
Switzerland	Leotchberg tunnel	33.0	2200	Gneiss, granite	42
Switzerland	St Gotthard tunnel	57.0	2300	Gneiss, dolomite	45
Italy-France	Blanc peak highway	11.6	2480	Granite, schist,	35

	tunnel			gneiss	
The Soviet Union	Alper Xie Wan Water diversion tunnel	48.4	1230	Porphyrite, breccia, tuff	33
Japan	New black water diversion tunnel	5.2	765	Gneiss	170
Italy-France	Frèjus New black third hydropower station water diversion tunnel	4.2	1610	Shale	29.5
Austria	Tauern tunnel	5.8	1570	Gneiss	23.9
China	The Chengdu Kunming Railway tunnel	6.1	1550	Limestone	28
China	Qinling railway tunnel	18.4	1600	granite, gneiss	40
China	The Gaoligong Mountain Railway Tunnel	39.6	800	Shale	40-75
China	Dayaoshan tunnel	14.8	880	Dolomitic limestone, tuff, slate, shale	30.5

Temperature prediction of deep buried tunnel.

Prediction formula. With the increase of depth, the ground temperature will increase, especially in the area of active fault zone, geothermal anomaly area, high ground stress or deep buried tunnel.with the increase of the depth of tunnel , there are two reasons of temperature increase ,firstly, the temperature gradient rise; Secondly ,the temperature rise caused by geothermal anomalies. In the area of hot springs out of dew, magmatic activity and radioactive elements exits, the soil temperature may be higher. The approximate formula for calculating the temperature of the tunnel can be calculated by the temperature gradient can be gotten by formula (1).

$$T=t+(H-h)\times G_T \tag{1}$$

Where, T is surrounding rock temperature，H is tunnel depth, h is constant temperature layer depth, G_T is geothermal gradient.

Classification of highland temperature. According to the regulations, it can be seen that, if the temperature is below 26°C in tunnel, the risk of heat damage caused by high ground temperature can be ignored or acceptable. The risk attributes to the primary level risk.

When the temperature is from 26°C to 28°C, it can be classified as secondary level risk.

When the temperature is over 28°C, the heat caused by high ground temperature is beginning to be serious, and the cooling measures need to be taken. The risk belongs to the third level risk.

When the temperature exceeds 30°C, the heat harm problem has been very serious, it must stop the operation, it can be classified as the fourth or fifth level risk.

Performance function model of high temperature risk. Performance function model of high temperature risk can be gotten by formula (2).

$$Z=R-S=T'-[t+(H-h)\times G_T] \tag{2}$$

Where, T′ is temperature classification threshold, t, H, h, G_T are random variables.

The occurrence probability of first class risk can be gotten by formula (3).

$$P_1=P((t+(H-h)\times G_T)\leq 26) \tag{3}$$

the occurrence probability of secondary class risk can be gotten by formula (4).

$$P_2=P(26<(t+(H-h)\times G_T)\leq 28) \tag{4}$$

the occurrence probability of third class risk can be gotten by formula (5).

$$P_3=P(28<(t+(H-h)\times G_T)\leq 30) \quad (5)$$

the occurrence probability of forth class risk can be gotten by formula (6).

$$P_4=P(30<(t+(H-h)\times G_T)\leq 35) \quad (6)$$

the occurrence probability of fifth class risk can be gotten by formula (7).

$$P_5=P((t+(H-h)\times G_T)>35) \quad (7)$$

Conclusions

When the temperature is less than 28°C, there is little effect on the construction process, it is necessary to carry on the routine management, and do not need to take measures to cool down. When the temperature is higher than 28°C, the cooling measures should be taken. When the temperature is over 30°C, the operation must be stopped. If there is high temperature phenomenon, the main measures can be carried out from following aspects.

Ventilation cooling. Increasing air quantity can greatly reduce the air containing heat, it is an effective cooling measures. Japanese experimental research results show that increasing the amount of ventilation, air temperature is greatly decreased, and the decreasing degree of the temperature will accelerate when the ventilation volume reached a certain amount, then the air temperature drops gradually slow down.

Individual protection. The refrigeration cost of individual protection is only about 1/5 of the other refrigeration costs. Personal protective measures include cool clothes, the working medium of cooling suit is dry ice, compressed air, cold water and self cooling effect cooling garment.

Reduce the heat source. For the high ground temperature tunnel, the main heat is rock dissipation heat. In the foreign countries, the research on the heat transfer insulation of the surrounding rock mass has been carried out. The basic conclusion is that the thermal insulation material is applied to the surrounding rock, and the higher of the temperature, the greater of the effect.

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