PROBLEMS OF FROZEN ROCK ENGINEERING IN THE DABANSHAN TUNNEL IN QINGHAI PROVINCE

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Abstract

The Dabanshan tunnel is located in the cold region of Qinghai province at an elevation of 3800 m above sea level. The mean annual air temperature is -3.1°C. The maximum thickness of material overlying the tunnel reaches more than 200 m and permafrost exists at the inlet and exit of the tunnel. The temperature field, the stress field and the paths of groundwater flow will be changed by the excavation and operation of the tunnel. The seasonally frozen rocks surrounding the tunnel will be changed into permafrost. The main patterns of frost damage in the tunnel are the swelling, cracking and peeling off of the tunnel lining; seepage of groundwater through the cracks; and frost and icings in the tunnel, including ice suspended from overhead. To prevent frost damage, the following measures are being taken: sprinkling Pu-insulation material on the lining, over-excavating at broken and weakened zones, providing waterproof plates on the inside of the lining and installing smaller parallel drainage tunnels under the main tunnel.

Introduction and study area

The Dabanshan tunnel is located near middle of Daban Mountain, which is part of the eastern branch of Qilian Mountains on the northeastern side of the Qinghai-Tibet Plateau. The tunnel goes through the ridge of the mountain which has maximum elevation of 4017 m. Permafrost exists, the annual air temperature is -3.1°C and the precipitation is high. The total length of the tunnel is 1530 m (see Figure 1).

The surrounding rock is mainly metamorphic schist, weathered to varying degrees, and tectonic crevices are widespread. A constant source of groundwater is present. Observations show that the overflow areas of groundwater in the tunnel come mainly from the broken zones of crevices and small faults, and from the interfaces between weakened, weathered rocks and the consolidated rocks. The groundwater comes from both the horizontal and vertical directions. In other words, an open talik or taliks exist between water-bearing
strata in the rocks and the upper part of the mountain, and surface waters could be the source of the groundwater. These areas, with broken rocks and seepage, provide the potential for frost and permafrost damage to the tunnel.

**Formation of permafrost and the creation of frost damage**

The temperature fields of the strata will be changed by the excavation and operation of the tunnel and the surrounding rocks will be seasonally frozen or become permafrost. According to the mean annual air temperature, the temperatures of the surrounding rocks and the groundwater, it is estimated that the mean annual air temperature will be 1 to 2°C lower in the tunnel than outside the tunnel. This implies that the mean annual air temperature in the tunnel will be colder than -4 to -5°C (Nie, 1988), which will cause the surrounding rocks to become frozen, forming permafrost. Ice layers, with thickness of 0.3 to 0.8 m, have been observed near the inlet and exit of the tunnel in winter during construction, and an ice layer 0.5 m thick was found 70 m from the exit of the tunnel in July. Numerical calculations show that the maximum depth of frost in the surrounding rocks can reach about 4 m in 1997. Within one or two years after the tunnel becomes operational, the surrounding rocks will be frozen in winter and partially thawed in summer. This is the so-called formation period for seasonally frozen rocks. Later, the surrounding frozen rocks will not be completely thawed by the heat and mass transfer in summer and will become permafrost, reaching a thickness of 3 to 4 m, or more.

On the one hand, the permafrost is good for tunnel stability because it prevents water seepage and increases the bearing capacity. On the other hand, the freezing of water in the pores and cracks induces frost heave, resulting in the cracking and peeling off of the wall lining and icings may appear in the tunnel. Investigations of the more than 30 tunnels constructed in the cold regions of China show that most of them are damaged to different degrees, and about 70% of the tunnels are very seriously damaged (Nie, 1989).

Theoretical analyses indicate that the frost heaving forces depend on the amount of ice, the frost temperature and the confining forces. A study of the frost heaving forces in the rocks surrounding the Dabanshan tunnel shows that the frost heaving forces increase with increasing frost depth and with increasing water contents. If the other conditions are the same, the frost heaving force increases with increasing strength of the surrounding rocks and is greater for granite than for chlorite schist.

**Measures preventing frost damage in tunnel**

The main causes of frost damage in tunnels in cold regions are water seepage and the freezing of the surrounding rocks. The optimal methods for preventing frost damage from occurring is to use insulation materials to prevent the surrounding rocks from freezing and to keep the drainage system open. The following measures are being taken in the Dabanshan tunnel:

1. **Sprinkling Pu-insulation Material on the Inside of the Tunnel Lining**
   The insulating layers can delay freezing in the surrounding rocks, can decrease the frost depth during the seasonally frozen period, and can also delay thawing in the surrounding rocks and decrease the thaw depth during the summer. Practice shows that the Pu-insulating layers not only are effective in heat preservation, but also provide water proofing.

2. **Over Excavation and Special Treatment at the Broken and Weakened Zones**
   The broken zones in the surrounding rocks, the tectonic crevice zones and the weathering-weakened rocks are areas of groundwater flow and the key places for frost damage in tunnels in cold regions. In the construction of the Dabanshan tunnel, these areas are overexcavated, filled with cement and treated with slurry under pressure.

3. **Placing Waterproof-Plates between the Surrounding Rocks and the Tunnel Lining**
   Seepage and the freezing of groundwater are the main cause of frost damage in tunnels in cold regions. To overcome the problem of water seepage in the

![Figure 2. The drainage system of the Dabanshan tunnel.](image-url)
Dabanshan tunnel, water-proof plates are used between the surrounding rocks and the lining to bridge areas where seepage would occur.

(4) Setting up the Completed Drainage System

It is not enough to use water-proof measures for most of the tunnels in the cold regions because the groundwater has a gravity-pressure head. To guarantee the safe operation of the tunnel, dredging and drainage of the groundwater must be taken to lower the crack or pore water pressure. Figure 2 shows the drainage system in the Dabanshan tunnel. The system consists of a sluiceway, a diversion tunnel, a blind well, a blind ditch and drainage plates. The sluiceway is shaped like a tunnel and located beneath the main tunnel excavation. This drainage system lowers the groundwater table and hence the frost heaving force. Additionally, insulation materials are used to prevent the drainage system from freezing in water.

Conclusion

1. The seasonally frozen rocks surrounding the tunnel in cold regions will be changed into permafrost by the excavation and operation of the tunnel.

2. The use of insulation materials to prevent the surrounding rocks from freezing and to keep the drainage system open is the optimal method for preventing frost damage from occurring.

References
