Thermal Performance of Embankment Within Crushed Rock Layer Along Qinghai-Tibet Railway

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In order to study the heat transfer process and the cooling mechanism within a crushed rock layer that is suitable for engineering construction in permafrost regions, in-situ measurements were conducted within an experimental section of a crushed rock-based embankment and a crushed rock revetment embankment in Beiluhe, Qinghai-Tibetan Plateau. The results show that both the crushed rock-based embankment and the crushed rock revetment embankment primarily have a cooling effect and protect permafrost from warming and thawing beneath the embankment. A different heat transfer process occurred within a different structural layer of crushed rock.

INTRODUCTION

Heat and mass transfer is a complicated process within a porous medium, including conductive, forced and free convective heat transfer processes (Trevisan, 1985). For a crushed rock layer with large pore space, heat transfer processes primarily depend on environmental conditions and pore space structure. In nature, a crushed rock medium with a large pore space usually leads to the anomalous spatial distribution of permafrost and permafrost temperatures (Harris, 1996; Gorbunov et al., 2001, 2004). For heat transfer processes within a crushed rock layer, various theories have been suggested to explain local anomalous low ground temperatures. A chimney effect occurs within the crushed rock layer when it is on a slope, resulting in low temperatures (Harris, 1998). Cheng (2003) noted that the Balch effect results in lowering the temperature within the crushed rock layer.

The natural phenomena are widely used to improve the thermal stability of permafrost under an embankment constructed in ice-rich and warm permafrost regions due to engineering thermal disturbance and climate change. In 1973, Cheng and Tong (1978) conducted the crushed rock embankment experiment at the Reshui colliery in the north piedmont of the Qilian Mountains. Results showed that the crushed rock embankment was efficient in protecting the permafrost (Wang et al., 1996). Goering (1998) and Goering and Kumar (1999) studied the crushed rock embankment under the asphalt pavement, and their results showed that natural convection occurred within the crushed rock layer when it was sealed by heat insulation, and without filling soil on it. Based on the hypotheses about what occurs within a crushed rock layer, Lai et al. (2003) and Jiang et al. (2004) used a numerical model to study temperature change and the cooling effect of embankments with a crushed rock layer according to the convective heat transfer theory for porous media. Their results confirmed the efficacy of the embankment with a crushed rock layer in protecting the permafrost from warming and thawing. The permafrost temperature monitored under the crushed rock layer embankment along the Qinghai-Tibet Railway indicated that the crushed rock layer was effective in cooling the embankment (Wu et al., 2005, 2008; Ma et al., 2008).

Laboratory model experiments showed that heat transfer is dominated by nature convection in a closed crushed rock embankment, forced air convection in an opened crushed rock embankment, force convection in a windward crushed rock revetment, and forced and natural convection in leeward crushed rock revetment (Zhang et al., 2005, 2006). Cheng et al. (2007) proposed the thermal semi-conductor effect of crushed rock based on the results of numerical simulations and laboratory model experiments, where the cooling effect of closed and sloping rock layers is in the form of the Rayleigh-Benard convection, while that of open and inclined rock layers is via the chimney effect and wind-forced convection (Cheng et al., 2007).

In order to clarify the cooling mechanism of a crushed rock layer in an open and closed system, and inclined state and the difference of the cooling effect among a crushed rock layer in an open and closed system and inclined crushed rock layer, we tried to find the reasons for the cooling effect that occurred within a crushed rock layer by in-situ experimental sections established in Beiluhe along the Qinghai-Tibet Railway. In this article, we discuss the thermal performance within a crushed rock layer in an open and closed system and inclined state by temperature variation within a crushed rock layer in an in-situ experimental section and the relationships between thermal performance within a crushed rock layer and wind speed outside a crushed rock layer.

EXPERIMENTAL DESIGN

The experimental sections were constructed in Beiluhe along the Qinghai-Tibet Railway in 2004. The mean annual ground temperature of permafrost was then about −1.4°C; the permafrost table ranged from 1.45 m to 1.6 m; and the ice-rich permafrost existed at a depth of 1.5 m to 10 m below the ground surface (Niu et al., 2002).