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Experimental studies on the ripped-rock revetment embankment in permafrost regions of the Qinghai–Tibet railroad

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Abstract

This paper reports experimental studies on the ripped-rock revetment embankment and the traditional embankment in permafrost regions of the Qinghai–Tibet railroad. The laboratory embankment models were designed according to similarity theory. Preliminary results show that the temperature distribution of the traditional embankment was asymmetric; the asymmetry was changed after the ripped-rock revetment was installed and the soil under the ripped-rock was cooled. Preliminary field experiment results show that the temperature trend under the ripped-rock was consistent with the result of the laboratory tests. The thickness of the ripped-rock on the south slope should be greater than 80 cm in Qinghai–Tibet Plateau. Experimental studies show that the ripped-rock revetment can cool the embankment and adjust the temperature distribution near the north and south slopes of embankment, and is an available technique to protect embankment from thawing settlement and longitudinal cracks in permafrost regions.

Keywords: Permafrost; North and south slopes; Thawing settlement; Ripped-rock revetment; Cool; Embankment

1. Introduction

The thermal status of permafrost is sensitive to the changes of ground surface temperature. Global warming and human infrastructures can increase the ground surface temperature, which will lead to extensive degradation of permafrost. Many studies have focused on this issue (Nelson, 2003). Degradation of permafrost can cause surface settlement, and structures are then subject to thaw-induced damages such as thawing settlement and longitudinal cracks of embankment. These kinds of damage have occurred in the construction of the Qinghai–Tibet railroad and the constructed Qinghai–Tibet Highway.

The Qinghai–Tibet railroad is under construction on "The Roof of the World" — the Tibetan Plateau. About 965 km of the 1118 km railroad is located 4000 m above sea level. The railroad covers 550 km of continuous permafrost and 82 km of island permafrost. Two hundred and seventy-five (or 50%) of the continuous permafrost is warm permafrost (mean annual ground temperatures 0∼−1.0 °C) and 40% is ice-rich permafrost. Climate warming on the Tibetan Plateau could increase the mean annual air temperature by 2.2 to 2.6 °C by 2050 (Qin, 2002), and construction of the Qinghai–Tibet railroad could lead to further degradation of the region's permafrost. Several techniques are being tested as means to cool the embankment (Ma et al., 2002; Yu et al., 2003, 2005; Cheng, 2005). Rock layer has cooling effect (Yu et al., 2004; Goering et al., 1996; Goering, 1998, 2003; Lai et al., 2003a,b, 2004). The

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field experiment data of the ripped-rock revetment embankment of the Qinghai–Tibet railroad can not yet predict the long-term results of the ripped-rock, because of the short observing periods (from August, 2002 to March, 2004) (the Interim Report of the Experiment Embankment of the Qinghai–Tibet Railroad, 2004). The primary objective here is to examine the temperature properties of the ripped-rock embankment and the traditional embankment when the ambient temperature is asymmetric, and to compare with field results.

2. Laboratory experiment design

The heat transfer process of embankments in cold regions is a nonlinear problem with phase change. The governing differential equations, the continuous condition equations, and the conservation of energy equations can be simply written as:

$$\frac{1}{a}\frac{\partial T}{\partial t}=\frac{\partial T}{\partial x}\left(\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(\frac{\partial T}{\partial z}\right) \tag{1}$$

where a is the thermal diffusivity; T is temperature; t is time.

The conditions at the fixed boundaries are:

$$T=T_{\mathrm{a}} \quad \lambda\frac{\partial T}{\partial n}=-\alpha(T-T_{\mathrm{a}}) \tag{2}$$

where T_{a} is the ambient temperature; λ is the thermal conductivity and α is the coefficient of heat convection.

Using the similarity transform method to deal with Eqs. (1)~(2), we obtain three similarity criteria: the Fourier Number $F_0=at/l$, the Nusselt Number $N_{\mathrm{u}}=\alpha n/\lambda$ and the temperature criteria $\theta=T_{\mathrm{a}}/T$. Relationships among the similarity constants are:

$$C_aC_t/(C_l)^2=1, C_aC_n/C_\lambda=1, C_{T_{\mathrm{a}}}/C_T=1 \tag{3}$$

where C_a is the similarity constant of thermal diffusivity; C_t is the time similarity constant; C_l and C_n are the geometric similarity constants; C_α is the similarity constant of the coefficient of heat convection; C_λ is the similarity constant of the thermal conductivity; $C_{T_{\mathrm{a}}}$ and C_T are temperature similarity constants.

Notes: the similarity constant is the ratio between the same physical quantities in the field model and the laboratory model. The precondition is that the two models have the similarity physical laws.

In this study, the experimental models were designed according to the field conditions of the Qinghai–Tibet railroad in the permafrost zone. The height of embankment is about 3~8 m. Because of the complicated field conditions, the experiments were conducted by using an approximated similarity method. The annual mean air temperature in the permafrost zone is about −4~−6.5 °C, and the freezing season is about 7 months each year. Generally, the ground surface temperature, which is determined by solar radiation and the complicated ground surface conditions, is much higher than that of the air. In fact, the

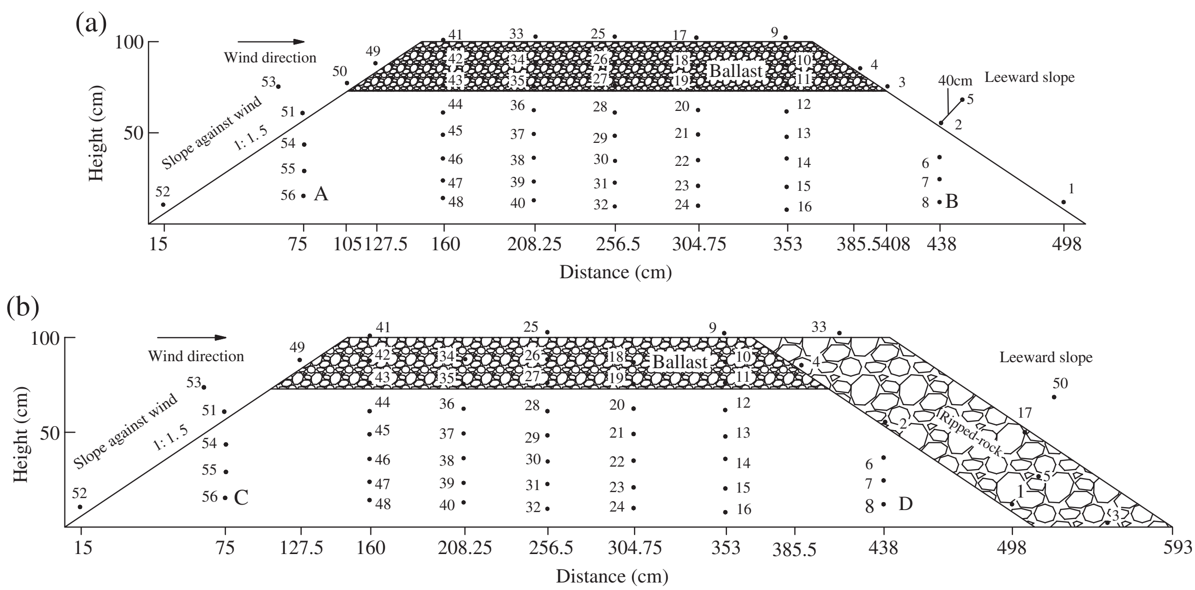

Fig. 1. Cross sections of embankment models. (a) Cross section of the traditional embankment. (b) Cross section of the ripped-rock revetment embankment.