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Numerical analysis for thermal characteristics of cinderblock interlayer embankments in permafrost regions

Mingyi Zhang*, Yuanming Lai, Dongqing Li, Gangqiang Tong, Jingbo Li

State Key Laboratory of Frozen Soil Engineering, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou Gansu 730000, China

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A B S T R A C T

This study numerically estimates the thermal characteristics of cinderblock interlayer embankments in permafrost regions. The characteristics of wind flow within the cinderblock interlayer are tested by wind tunnel experiment. The tested results, as well as the heat and mass transfer theories, are used to develop a conceptual and numerical model of cinderblock interlayer embankments without and with ventilated ducts. The model is conducted to evaluate the cooling capacity of the cinderblock interlayer embankments of expressway without and with ventilated ducts. The numerical results indicate that the cooling capacity of cinderblock interlayer embankment without ventilated ducts enhances with the increase of cinderblock interlayer thickness. The permafrost under the embankment, however, is still warmer than that under the natural ground surface. This warming can be offset when ventilated ducts are added to the top of the cinderblock interlayer. Therefore, the cinderblock interlayer embankment with ventilated ducts can be an effective measure to ensure the stability of expressway in warm permafrost regions.

1. Introduction

On the Earth, the Permafrost regions are about 25% of land area [1]. Many roadways, e.g. the Qinghai–Tibet Highway and Qinghai–Tibet Railway in China, the Alaska Railway in the USA and the Baikal-Amur Railway in Russia, had been constructed in the areas underlain by permafrost. Furthermore, some roadways are currently under plan. These constructions often result in a warmer surface condition, and tend to warm the permafrost and make it susceptible to thaw. Thaw settlement of permafrost will result in instability and even failure of construction. This type of permafrost degradation beneath an embankment would be magnified under scenarios of global warming [2,3]. A number of measures can be taken to lower the ground temperature and to counteract the effect of climate warming, e.g. the construction of the Qinghai–Tibet Railway with an application of a series of cooling techniques to protect the underlying permafrost and ensure the stability of railway embankment [4]. Duct-ventilated embankment, crushed-rock embankment and thermosyphon embankment have all shown to provide practical cooling effects in many permafrost regions [4–9].

However, such degeneration can be further amplified under the high-grade, wide highways. In China, the under-plan Qinghai–Tibet Expressway would likely experience degradation of the underlying permafrost because compared with the railway's surface, the asphalt surface potentially results in a higher surface temperature. The mean annual temperature of dark asphalt surface can be up to 6.5 °C higher than that of surrounding air on the Qinghai–Tibet Plateau [10]. Some highway engineering projects in cold regions (e.g. Qinghai–Tibet Highway and Qing-Kang Highway), have suffered from degradation of the underlying permafrost. Damages of these roadways often occur even if the cooling measures have been adopted. Besides, the surface of one-way expressway is usually beyond 10 m wide according to the Design Specification for Highway Alignment in China [11]. More heat will be absorbed through the wide upper surface, so that the degradation of the underlying permafrost will be accelerated. Therefore, a direct adoption of the cooling method that used for the railway to the Qinghai–Tibet Expressway possibly cannot ensure a long-term thermal stability. It is thus urgently necessary explore some economical, safe, and effective means and techniques to protect the underlying permafrost and ensure the thermal stability of the under-plan expressways on the Qinghai–Tibet Plateau.

This permafrost degradation issue under an expressway may be remedied by use of a highly porous interlayer embankment. Although the porous crushed-rock interlayer embankment has

* Corresponding author. Tel.: +86 931 4967296.
E-mail address: myzhang@lzb.ac.cn (M. Zhang).

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