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A numerical model of the coupled heat transfer for duct-ventilated embankment under wind action in cold regions and its application

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Abstract

The duct-ventilated embankment, as a special embankment structure, has been used to protect the underlying permafrost from thawing in Qinghai-Tibetan railway construction of China. For cold regions engineering, the temperature is the most important factor that determines the stability of construction, and wind can directly affect the temperature distribution in the construction. To research the stability of the duct-ventilated embankment under wind action, based on the wind, temperature and geology conditions of Qinghai-Tibetan Plateau, a three-dimensional numerical model of the coupled heat transfer for duct-ventilated embankment, which was composed of the air convective heat transfer problem between inside and outside duct, the coupled heat transfer problem between airflow and duct wall, and the heat conduction problem with phase change in roadbed, was analyzed to determine the temperature and velocity characteristics in the ventilated duct, as well as the temperature fields of the duct-ventilated embankment. The numerical model can reasonably solve the coupled heat transfer problem for duct-ventilated embankment; furthermore, from the results, it was found that, on the assumption that the air temperature will be warmed up by 2.2 °C in the future 50 years and in the areas where the mean annual air temperature is −4.0 °C, the duct-ventilated embankment structure can be an effective measure to decrease the ground temperature beneath it and ensure the stability of permafrost roadbed.

Keywords: Numerical model; Duct-ventilated embankment; Coupled heat transfer; Temperature and velocity characteristics; Wind action; Cold region

1. Introduction

The permafrost area of the earth is about 25% of the land (Zhou et al., 2000). With the development of the economy, railway/highway construction projects are being constructed or planned in the areas underlain by permafrost. For cold regions engineering, the temperature is important to determine the stability of construction. When the embankments are constructed, they typically have a large influence on the thermal regime of the ground. Because of global warming and existence of highway/railway, the permafrost in these regions tends to warmer and therefore susceptible to thaw (Wang et al., 1996). Thaw settlement of permafrost typically results in instability and failure of the construction, especially in some high ice-content permafrost regions. Therefore, in the construction of Qinghai-Tibetan railway of China, to ensure the stability of railway embankment and protect the underlying permafrost, a series of techniques were employed, e.g. duct-ventilated

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embankment, crushed-rock embankment and thermosyphon embankment (Ma et al., 2002). The cooling effect of duct-ventilated embankment has been recognized, especially in windy Qinghai-Tibetan Plateau.

Recently, some studies have been done on the cooling effect of the duct-ventilated embankment with a wind boundary. Yu et al. (2003) carried out a laboratory investigation on the temperature characteristics of the ballast embankment and the duct-ventilated railway embankment with a constant wind velocity. The results showed that, due to the effect of airflow, the duct-ventilated embankment structure can quickly decrease the temperature of the underlying soils; Niu et al. (2003) found that the ventilated duct can effectively cool the embankment fill using data of the experimental duct-ventilated embankment along Qinghai-Tibetan railway; Lai et al. (2004), on the assumption that the temperature is evenly distributed at the inner wall of ventilated duct, used finite-element method to analyze the temperature fields of the duct-ventilated embankment, and the results indicated that the embankment structure can ensure the multi-annual stability of the underlying permafrost. However, the flow pattern of air in the ventilated duct and the coupled convective heat transfer problem between air and duct were not mentioned in these studies. Research (Liu and Ma, 2002; Rao and Liao, 2005; Lai et al., 2005) showed that the flow pattern of fluid will directly affect the temperature distribution inside duct and the heat transfer between fluid and duct. Wind can enhance the heat exchange between surroundings and structure, and directly affect the temperature distribution of construction. Herein, a three-dimensional

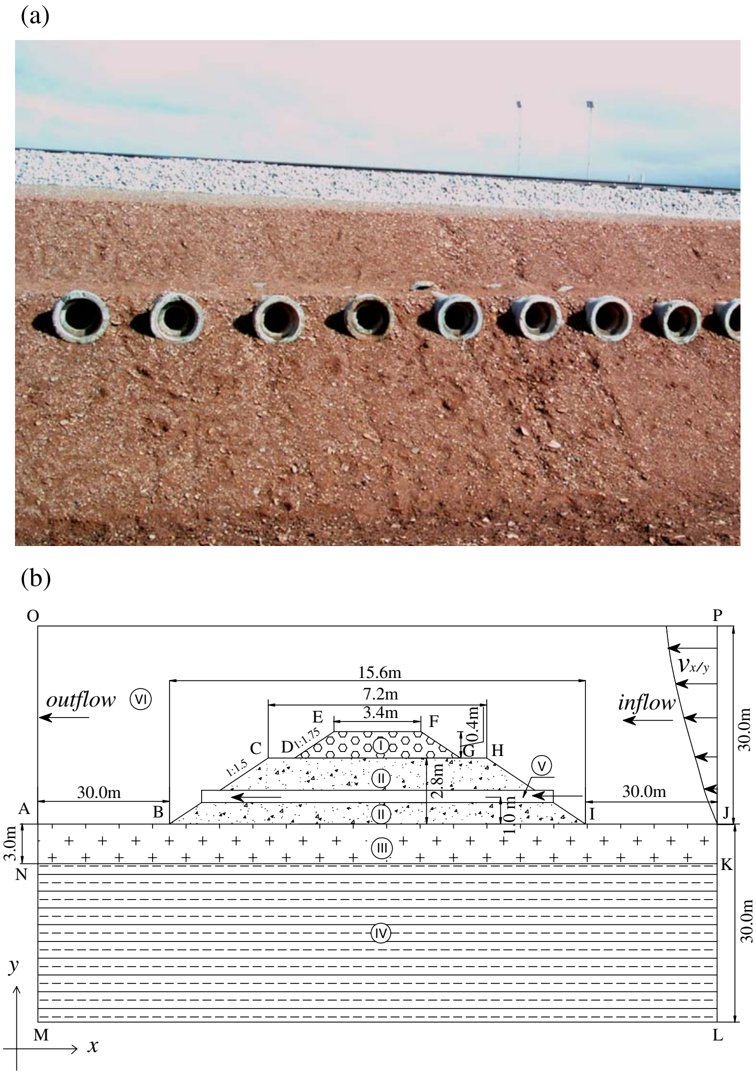

Fig. 1. Duct-ventilated embankment model: (a) experimental embankment model; (b) computational embankment model.