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Analysis on thermal stability and deformation stability of CMR

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ABSTRACT

In permafrost regions, embankment stability has been destroyed with longitudinal cracks primarily caused by transverse asymmetric settlement. And shady–sunny slope effect is a principal factor which might result in embankment asymmetric settlement. Based on field data of some typical sections along the Chai–Mu Railway (simply called CMR) with obvious shady–sunny slopes, which is located on the Qinghai–Tibet Plateau, the ground temperature characteristics and settlement deformation properties of the embankment have been analyzed. This paper has studied how the different engineering measures, including rubble ventilation embankment, thermal pipe revetment embankment, rubble and thermal pipe revetment joint embankment, did influence the shady–sunny slope effect. The results show that: (1) Both thermal pipe revetment embankment and rubble ventilation embankment have perfect effect on cooling the roadbed in permafrost regions. However, for thermal pipe revetment embankment, the sunny–shady phenomenon and asymmetric settlement of embankment have been avoided if thermal pipe has been strengthened in sunny side. For rubble ventilation embankment, the sunny–shady effect has been hardly eliminated even though the rubble has been strengthened in sunny side. Although some composite embankments, such as the rubble and thermal pipe revetment joint embankment, have been successfully applied in the Qinghai–Tibet Railway, it is difficult to completely eliminate the sunny–shady slope problem along the CMR because of the complicated engineering geological conditions and the bad permafrost environments. (2) Along the CMR, in all common embankments — the observed results show that the settlement deformation is within 30 cm that is within the settlement standards of the National II Class Railway. Even the settlement deformation of thermal pipe subgrade and rubble ventilation embankment was able to meet the National I Class Railway standards — 20 cm. (3) On the basis of the above, some corresponding countermeasures and advice are proposed. First, rational use of the synthetic application of engineering measures must be taken. For example, let the structural mechanics measures and temperature controlled measures unify altogether to prevent longitudinal cracks. Second, the specific work conditions and details such as engineering geological condition, permafrost environments as well as other local factors including the slope orientation have to be taken into account in order to put forward rational engineering measures and accurate design parameters. Finally, it is essential to protect and to comprehensively evaluate the permafrost environment, which is the ultimate basis of permafrost engineering.

1. Introduction

In permafrost regions, construction of embankments has changed the thermo-physical features of natural ground surface and atmosphere, influenced thermodynamic and dynamic stability of frozen soil layers, and complicated temperature fields of frozen soil embankment (Ma et al., 2005; Qi et al., 2007; Sun et al., 2004; Yu et al., 2007). When the two embankment slopes are south-facing and north-facing, respectively, which is called shady–sunny slope in Chinese, the difference of thermal boundary conditions such as solar radiation and surface turbulent flow will induce transverse asymmetry of temperature field, and this will lead to a multitude of problems in permafrost roadbeds. And there extensively exists these kinds of phenomena in both warm and low temperature permafrost regions (Liu et al., 2002). The thermal difference of the shady–sunny slope results in there is an unbalanced freeze–thaw condition between both sides of the embankment, which leads, inevitably, to transverse differential settlement. As time goes by, the differential settlement will be aggravated, and finally the embankment stability is destroyed with longitudinal cracks caused by asymmetric settlement of permafrost (Wang and Dou, 2004; Wang et al., 2006). Based on observed field temperature data in Beiluhe on the Qinghai–Tibet Plateau, Sheng et al. (2005) analyzed the thermal difference between the shady and sunny slopes, and pointed out that the thermal difference can lead to development of embankment longitudinal cracks. Lai et al. (2004) recommended that the embankment

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disease that results in uneven settlement with longitudinal cracks can be eliminated by paving ripped-rocks of different thickness on the sunny and shady slopes, respectively.

Cheng (2003) showed that some local factors including slope orientation can change permafrost distribution and may cause some engineering damages such as longitudinal cracks. The investigation was done by analyzing both observational geo-temperature and deformation data of the embankment in experimental section K369+100 along the National Highway 214 on the Qinghai–Tibet Plateau. Also, the fundamental cause of the embankment transverse asymmetrical thermal regime and asymmetrical deformation was discussed (Chou et al., 2009). The longitudinal cracks are a very common permafrost embankment disease, which has attracted the attention of more and more researchers (Mao et al., 2010; Pei et al., 2006; Wu et al., 2002; Xu, 2010; Zhang et al., 2003). According to field observation, the longitudinal cracks are distributed mainly over the sunny side of high embankments in unstable permafrost regions. Moreover, the longitudinal cracks developing along the sunny side covers more than 70%. And the longitudinal cracks appear not only in common embankments, but also in reinforced embankments, such as thermal pipe embankment, ripped-rock revetment embankment, insulation embankment and so on (Su et al., 2004; Wang et al., 2003). Through field investigation, Wu et al.(2005) pointed that a better thermal stability situation will be developed under conditions where the temperature near the permafrost table beneath the rubble embankment has largely dropped in cold permafrost regions. But in warm permafrost regions, even the permafrost table has highly raised the annual thermal imbalance of permafrost and temperature will rise, and it is disadvantageous for the thermal stability of permafrost. In the warm permafrost region, only the embankment shady side can be better cooled by adopted rubble layer but in the cold permafrost region, the rubble ventilation embankment not only has cooled the whole subgrade, but also has played a certain role in restraining the sunny–shady effect (Chen et al., 2011). Liu and Li (2008) predicted the temperature field of embankment with crushed rock protection in the future 50 years by applying the transient thermodynamics FEM method. The computation results show that the temperature difference between the sunny slope and the shady slope has existed at all times, but the difference on the same days and months has varied little with year. Therefore, how the different engineering measures have influenced the shady–sunny slope effect is an important subject worth studying.

The Chaidaer Muli Railway, simply called the CMR, is the first local railway with a total length of 142 km in northeastern Qinghai Province, China. It starts in Chaidaer County (100°25′55″E, 37°35′40″N) and ends in Muli Country (99°11′00″E, 38°08′38″N). Fig. 1 gives the geographical location of the CMR. Topographically, it passes through the Datong River valley, the Datong Mountains and the front edge of the Tuolai Mountain in the central-eastern Qilian Mountains. The railway broadly runs from southeast to northwest. The elevations of this region range from 3600 m to 4100 m and the average annual air temperatures vary from about −2.4 °C to −5.8 °C. According to the meteorological data, the minimum air temperature is −40 °C and the maximum air temperature is 17 °C, respectively. There is rich rain and snow, and swamps as well as marshes are both developed. The annual precipitation along the CMR is approximately 500 mm·a^{-1}. The vegetative coverage is more than 60% in most of the permafrost regions, and the wetlands are widely distributed. About 77 km of all the CMR runs across wetlands. The permafrost is discontinuous and unstable with average annual ground temperature ranging from −1 °C to 0 °C. The ice contents in most permafrost regions are also very high.

During the construction of CMR, based on the experience of the Qinghai–Tibet Railway, a number of engineering measures were taken to alleviate the sunny–shady effect. This paper will study the ground temperature characteristics and the settlement deformation properties of the embankment through analyzing the observation data of some typical embankment sections along the CMR. Also, that the positive cooling engineering measures, including the rubble ventilation embankment, the thermal pipe revetment embankment, the rubble

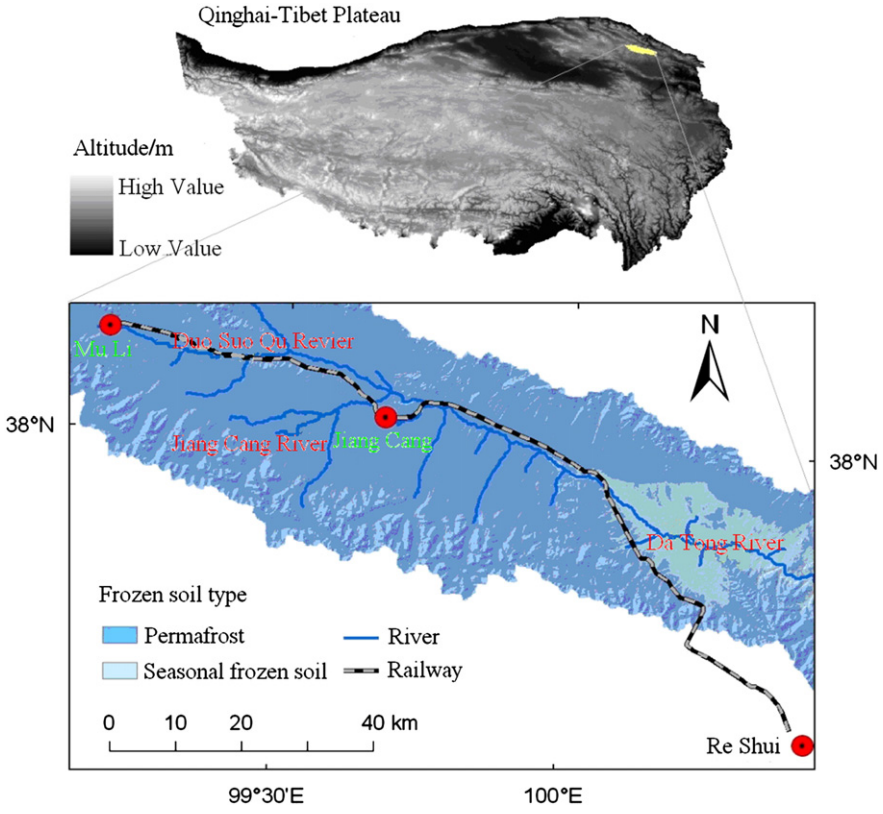

Fig. 1. The geographical location of the CMR.