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Study on the relationship between the shallow ground temperature of embankment and solar radiation in permafrost regions on Qinghai–Tibet Plateau

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A B S T R A C T

The temperature field of permafrost embankments is a key factor to determine the embankment stability. On the basis of observed climate data and field-temperature values in Beiluhe on the Qinghai–Tibet Plateau, this paper uses statistics methods to set up a regression equation between the temperature at shallow ground depth (0.5 m) and the net radiation on embankment horizontal surface. There is a good linear relation between the temperature and the net radiation after the phase difference is removed. Moreover, an empirical formula consisting of the shallow-ground temperature of (0.5 m) and the direct solar radiation is proposed. It is also suitable for the area having high elevation at the Beiluhe site. These formulas combining with the law of documents and materials suggest that there exists an obvious linear relation between the temperature on horizontal surface and the direct solar radiation. However, there is hardly linear relation between the temperature and the direct solar radiation on embankment slopes. The key factor is that the railway embankment slope has a relatively heavier gradient. The slopes with heavier gradient have different heat transfer characteristic during a specific year. In summer, the sun is shining straight on the ground, which results in a relatively lower direct solar radiation on slopes; however, because of diffuse radiation and higher temperatures of the horizontal surface, temperatures on slopes are relatively higher. In winter, the direct solar radiation on shady slopes is even zero, meaning that there is almost no direct solar radiation. Thus, the relations between the temperature and the direct solar radiation on slopes are more complicated.

1. Introduction

When the embankment is built in permafrost regions, the permafrost is regarded as a special ground material whose stability is influenced by combined factors, such as the mean annual air temperatures, road trends, embankment heights, drainage system, road surfaces and so on. Engineering damages of the built embankment are mainly caused by thaw settlement of permafrost. The Qinghai–Tibetan Railway passes across more than 550-km permafrost regions. The railway structural stability as well as its useful life depends directly on thermal regime of the underlying permafrost. The construction of embankments changes the thermophysical features of the natural ground surface and microclimate, and influences the thermodynamic and dynamic stability of the frozen soil layers, complicating the prediction of the frozen soil embankment temperature fields. The ground-surface temperatures and the embankment horizontal surface have been investigated by national and international scholars (Goering and Kumar, 1996; Li et al., 2000; Wu et al., 1988). On the basis of field data from the Tibetan Plateau in a few decades and of the boundary layer theory, the fixed boundary temperature of the permafrost embankment can be expressed by the trigonometric functions (Zhu, 1988). Hu et al. (2002) have given an empirical formula to calculate the embankment surface temperatures according to the solar radiation in Amdo of the Qinghai–Tibet Plateau. Wang and Cheng (2002) have set up a commonly practicable thermodynamics numerical model (RSTM) to assess the environment ground surface, the top surface, and the shady and sunny side slope surfaces of the embankments along the Qinghai–Tibetan Railway. The model is suitable for quantitative research and for applications to the heat status of the embankment surface, with various slopes and directions, along the whole line of the Qinghai–Tibetan Railway. In accordance with the thermal analysis, Li et al. (2000) gave the calculation equations of the earth surface and embankment surface. Through the air temperature data and **n** factor, the mean annual temperature is calculated by functions (Goering and Kumar, 1996). These methods have provided a computing method for the temperatures of embankment horizontal surface and slopes. However, they need field meteorological data. Although field data can actually reflect the embankment temperature field, both field monitored ground temperature and meteorological data are difficult to monitor especially over long periods of time because of the specific natural environment of Qinghai–Tibet Plateau.

In a word, nearly all energy on earth comes from the sun either in an indirect or straight way, in the form of heat rays and light rays

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(Zhang and Zhang, 1998). Solar radiation includes direct radiation and diffuse radiation. In sunny weather, the direct radiation back to the earth surface makes up approximately 90% of the all radiation, and the diffuse radiation only accounts for the remaining 10%. However, on cloudy days, radiation back to the earth surface is mostly the diffuse radiation. Direct solar radiation is the heat source to warm the earth, and is a most important factor to affect the permafrost embankment stability (China Solar Energy Net). On the Qinghai–Tibet Plateau, the considered facts include the high altitude, thin and dry air, a great transparency factor, long sunlight hours, little rain, a short distance traveled by solar radiation, and a hardly weakened solar radiation (Sun, 2005). The influencing factors such as cloud, precipitation and wind thus complicate the embankment temperature field in permafrost region, but the direct solar radiation is the key factor (Hu et al., 2002). Field data (Chou et al., 2008) and associated documents (Sun et al., 2004) indicate that the temperature difference on slopes results principally from the difference in the amount of solar radiation on the slopes. Moreover, considering that the relation of the radiation and temperature on slopes is hardly linearly, Chou et al. (2008) used statistics methods to set up a regression equation between the temperature difference and solar radiation difference on slopes. However, the relationship between the temperature and solar radiation was not in discussions in this article. The field temperatures presented in this paper indicate temperatures at the depth of 0.5 m under the slope surfaces. Field observation shows ground temperatures at 0.5 m are hardly influenced by random factors such as cloud and wind. This paper will set up a regression equation between the temperature and solar radiation on embankment horizontal surface. It will discuss why there is hardly linear relation between the radiation and temperature on slopes.

2. Location and method for observation

The observation site lies on a plain in the southern part of the Beiluhe basin (Fig. 1) on the Qinghai–Tibet Plateau, belonging to diluvial alpine plain physiognomy. The observation sites are located between DK1139 + 618 and DK1139 + 950 (the design milepost of Qinghai–Tibetan Railway). The sites have elevation ranging from 4635 m–4639 m. The embankment heights range from 2.5 m to 4.5 m and the fill is gravelly soil. The vegetation coverage is less than 20%. According to drilling-hole data, the ground layers consist mainly of mudstone, sandstone, clay and silty sand. The permafrost table is at about 2.5 m. A great deal of ground ice exists in permafrost at the test site. The range of mean annual ground temperature is from −0.28 °C to −0.69 °C. The type of frozen soil is warm instable permafrost and warm highly instable permafrost. The strike of the experimental embankment is SE40°. After the embankment was finished, the sunny and shady slopes of embankment are obvious (the sunny slope is southeast-facing and the shady slope is northwest-facing). Under the embankment surface at three experimental sections (DK1139 + 670, DK1139 + 820 and DK1139 + 940), the ground temperatures at a depth of 0.5 m began to be observed after the embankment had been finished for half a year. The data logger is composed of thermal-susceptible resistance sensors and Fluke IV multimeters with a 0.1 Ω precision. The space between two probes is 0.5 m. The frequency of observation is once every 10 days. The position of temperature probes is shown in Fig. 2. The observed data before June 29, 2003 indicate that shallow ground temperatures and their changes are similar at the three test sections. Therefore an analysis for the observed data at section DK1139 + 670 is adequate to demonstrate the ground temperatures observed at the observational sites. The analysis centers on the relationship between the mean annual shallow-ground temperature (0.5 m) and the received solar radiation. Fig. 3 shows the 0.5 m-depth ground temperatures from June 2002 to Sep 2004.

Based on field data, many scholars indicated that there was good linear relationship between the solar radiation and the net radiation (Fleischer, 1953; Shaw, 1956). So, we presume there is good linear relationship between solar radiation and the temperature. That variation trend of temperature changing with time is similar to that of

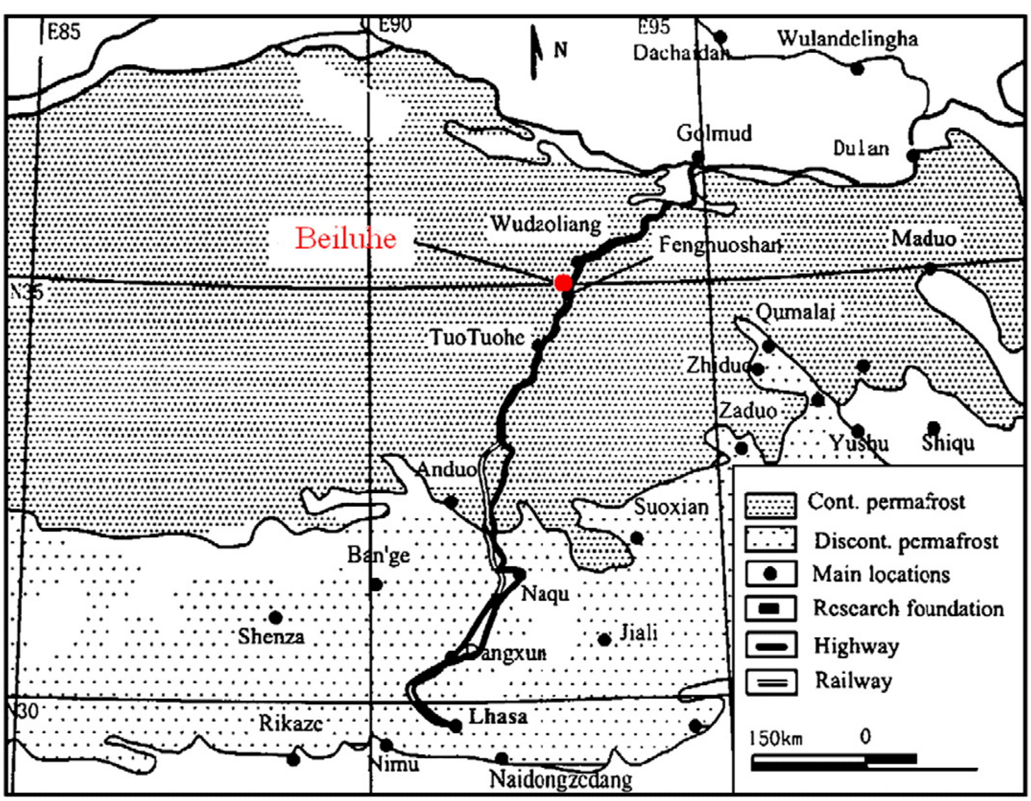

Fig. 1. Permafrost distribution on the Qinghai–Tibet Plateau and the observation site.