Cold Regions Science and Technology 153 (2018) 25–32

Contents lists available at ScienceDirect

Cold Regions Science and Technology

journal homepage: www.elsevier.com/locate/coldregions

Delamination frost heave in embankment of high speed railway in high altitude and seasonal frozen region

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ARTICLE INFO

Keywords:
High altitude
Seasonally frozen soil
High-speed railway
Frost heave
Coarse graded soil

ABSTRACT

The Lanzhou-Xinjiang high-speed railway is the first and the longest high-speed railway built in the high altitude and seasonally frozen areas in the North-west China. Frost heave is a basic problem need to be studied and prevented for the safe operation of the railway. In this paper, frost heave was monitored in four sections along the railway from 2015 to 2017. The result show that the largest frost heave occurs in the middle layer (0.5–1.5 m) with the maximum frost heave ratio of 2.52%. However the coarse filling material of the layer is considered to be unsusceptible to frost heave. In laboratory, grain size tests and frost heave tests were conducted, showing that there exists an increasingly linear relationship between the fine content (size smaller than 0.25 mm, $P_{0.25}$) and the frost heave ratio. However, $P_{0.25}$ is suggested to be less than 11.3%. The monitored results also show that the frozen depth increases as an exponential function of time and the maximum frozen depth in embankment ranges from 3.0–3.2 m, while in the natural frozen depth, it was only 1.8 m, recorded in 2016–2017. The increased frozen depth might promote the development of frost heave, which was observed at three layers in different depths (0–0.5 m, 0.5–1.5 m, and 1.5–2.7 m), along with the variations of the moisture content and the ground temperature. For a few study results can be refereed, the frost heave characteristic of embankment filled with coarse-grained soil, and the relationships among of the ground temperature, water content, $P_{0.25}$ content and frost heave amount, can provide a better understanding of the frost heave mechanism of high-speed railway embankment, so that to benefit high speed railway designing in high altitude and seasonally frozen regions.

1. Introduction

In China, the high population and long distance between provincial cities make many travelling difficulties. Especially in North-west China, the undeveloped traffic conditions are the important factors that restrict the economic development. To change such a situation, it was planned that the high-speed railway (HSR) in China would reach to 3×10^4 km in distance in the year 2020. However, around 72% of China's land territory are occupied by permafrost and seasonal frozen ground (Li et al., 2008). The cold weather and the corresponding frost heave of the railway embankment take great challenges to HSP constructions. Such problems have occurred in the first cold region HSR, the Harbin-Dalian HSR in North-east China (Liu et al., 2012, 2016). The strict deformation control of HSR embankment lead the frost heave prevention be the key point in HSR constructions in cold regions. According to the past experiences, the frost heave of an embankment is basically related to ground temperature field, soil type (Liu et al., 2012, 2014) and water content (Niu et al., 2017). The frost heave mechanism obtained in earlier studies were mainly from experiments on fine particle soils (Ćwiąkała et al., 2016; Konrad and Lemieux, 2005; Yue et al., 2013). However, the embankment of the HSR is filled with coarse grained soils. Therefore, the frost heave calculation methods were also studied and evaluated, based on indoor experiments and field monitoring (Zhang et al., 2015; Li et al., 2017). From the aspects of factors influencing frost heave, three main methods can be employed to control or prevent the frost heave. The one and also the simple method is

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https://doi.org/10.1016/j.coldregions.2018.04.017
Received 21 November 2017; Received in revised form 9 February 2018; Accepted 24 April 2018
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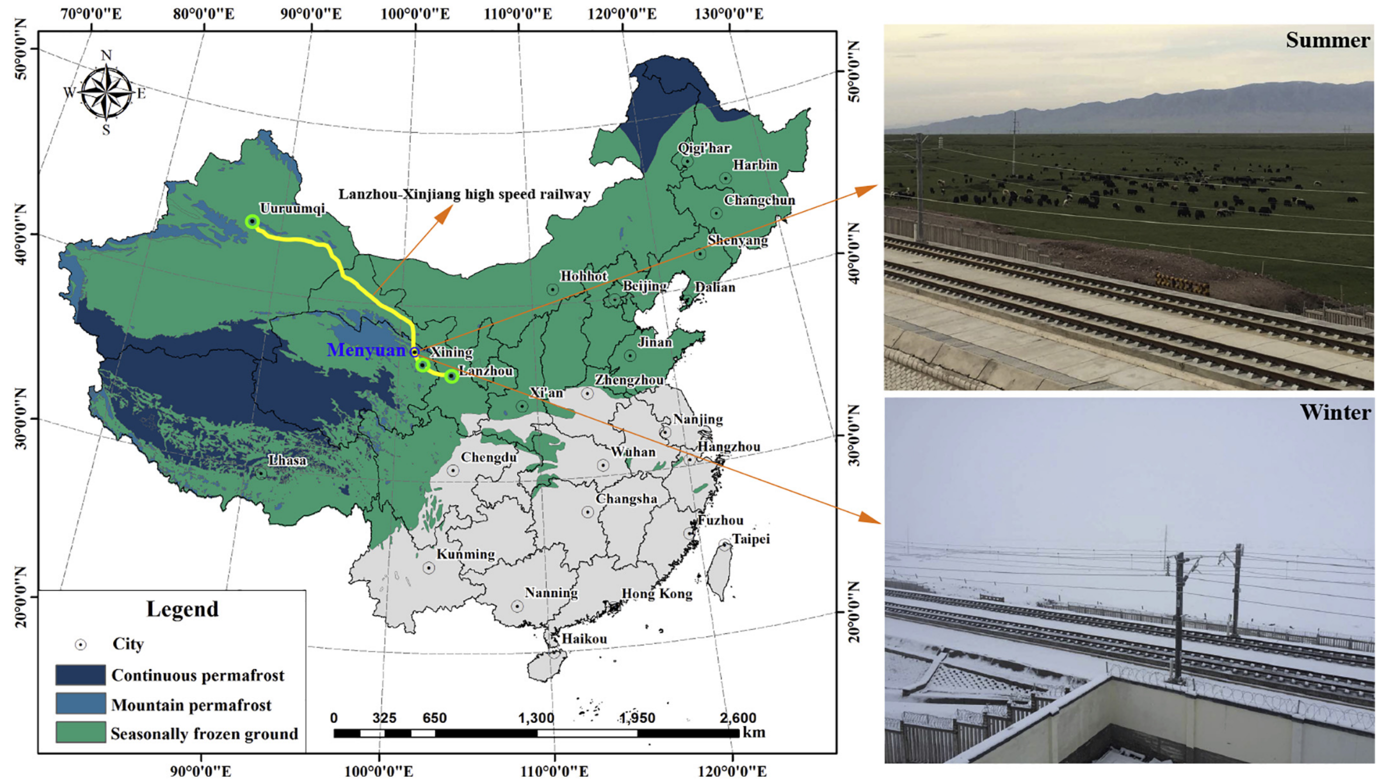

Fig. 1. Frozen ground distribution in China and the studied position along the Lanzhou-Xinjiang high speed railway.

replacing the subgrade soil or using susceptible materials. The most common filler is A/B group soil or grained crushed rock, like that used in the Harbin-Dalian HSR. However, frost heave still happened and it was thought than even dynamic load would cause frost heave (Sheng et al., 2014). The other two methods are to control temperature and water content of the soils. In engineering practice, the three methods are always comprehensive adopted, liking the constructions of the Harbin-Dalian HSR and the Lanzhou-Xinjiang HSR, in North-east China and North-west China, respectively. The two railways have been completed, using the comprehensive frost-heave-preventing methods, yet different degrees of frost heave deformation were monitored in the embankments during the operation (Niu et al., 2013; Tai et al., 2017; Xu et al., 2011). Therefore, influence of the fine particle content in coarse grained soils still needs to be studied, as what Vinson et al. pointed out early in 1986 (Vinson et al., 1986).

The common understanding is that the fine particle content is a key factor causing frost heave. Currently, many experimental investigations have been conducted to put forward the control standards of the fine particle content as well as to state the requirement of certain environmental elements. Brandl (2008) found that when the fine particle content was lower than 7%, even if the water content was high, the frost heave amount was relatively limited. Zhao et al. (2014) noted that the frost heave ratio changed greatly when the A/B group soil was frozen from positive temperature to −5 °C. Moreover, frost heave still occurred when the fines content was less than 15%, according to the laboratory testing results. Akagawa and Hori (2015) confirmed that the fine minerals in crushed rock were susceptible to frost heave. Gao et al. (2018) conducted a series of 1-D freezing experiments and inferred that the total frost heave amount was proportional to the amount of water intake, and it increased linearly with the increase of fines content. In these studies, the grain size smaller than 0.075 mm is generally considered as a fine particle. In addition to the fines content, the water content is also an important factor that affects the frost heave of coarse-grained soils. Wang et al. (2016) pointed out that the moisture content produces the most significant effect on the frost heave ratio of graded crushed rock. Therefore they suggested that the moisture content of graded crushed rock should be maintained below 5%, in order to prevent frost heave development. Zhang et al. (2007) thought that water content was the most important factor affecting the frost heave of coarse-grained soils. Form the studies mentioned above, the relationships between frost heave amount and temperature, fines content, and water content etc. are easily obtained through laboratory tests, as the testing conditions can be controlled. However, the real frost heave mechanism and the influence factors in a real project have been rarely studied due to complex environment, geological and construction conditions.

The Lanzhou-Xinjiang HSR crosses high altitude which is sometimes defined to begin at 2440 m to 4270 m above sea level [Cymerman A and Rock P B, 1994] and seasonally frozen regions in North-west China. It was opened to traffic in 2014, and frost-heave of the embankments has not been reported. For supporting a better understanding of the frost-heave of the HSR, the in-situ frost heave deformation monitoring was conducted, along with the related in-door frost heave tests. The relation of delamination frost heave with temperature, water content, $P_{0.25}$ content (the percentage of grain size less than 0.25 mm) and the primary affecting factors are discussed in this paper. The results might benefit the understanding of frost heave property of coarse soils and HSR designing in high altitude and seasonally frozen regions.

2. Engineering background and climate conditions

2.1. Engineering background

The Lanzhou-Xinjiang HSR adopted ballastless tracks, the construction was begun in November 2009 and finished as well as opened to traffic in December 2014. The overall length of the railway is 1065.8 km and the embankment length is approximately 600 km. The designed speed of the railway is 250 km/h. There is a 110-km-long section where the altitude is over 3000 m. In this section, four monitoring sections are situated in the Menyuan County of the Qinghai Province, China (Fig. 1). The Menyuan County is located in an

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