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Analysis of railway subgrade frost heave deformation based on GPS

Fuxun Ma[a,*], *Ruijie Xi*[b], *Nan Xu*[c]

[a] *Research Center of GNSS, Wuhan University, Wuhan 430079, China*
[b] *School of Geodesy and Geomatics, Wuhan University, Wuhan 430079, China*
[c] *Center of Earth System Sciences, Tsinghua University, Beijing 100084, China*

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ABSTRACT

In order to analyze the connection between the railway subgrade frost heave deformation and temperature variation, five GPS stations' data were used to monitor the deformation on a certain section of railway subgrade in northeast China. GAMIT software is used to process the data, providing daily solution, daytime solution and nighttime solution. Vertical trends of these five stations were analyzed to investigate frost heave effect on railway subgrade deformation. The results show that the temperature difference between daytime and night induces stations, significant vertical displacement, and the temperature difference between seasons causes settlement of station which appears linear trend.

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1. Introduction

With the development of high-speed railway industry, deformation of railway subgrade caused by frost heaving happens frequently in the high-latitude area in China. The major cause for the railway subgrade frost heave deformation is the freeze-thaw action of the permafrost. Due to the influence of the climate and the geographical condition in the northeast China region, the permafrost along the railway is the biggest obstacle to the normal operation of high-speed railway [1–3]. Using GPS technology to monitor the sedimentation of railway subgrade and to realize continuous observation of the real time data can obtain a global understanding of the changes of railway subgrade at different stages, in order to better master the operation status of the railway subgrade and guarantee route security [4–6]. Therefore, using GPS technology to get the deformation information of railway subgrade in the permafrost area is significant.

Zhang et al. [7] establishes a multi-antenna system with one GPS receiver, realizing the long-distance auto-

* Corresponding author.
E-mail address: fuxunma@whu.edu.cn (F. Ma).
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monitoring of the sedimentation of railway subgrade frost heaving. In this paper, Kalman filtering is also used to achieve the positioning accuracy of 2 mm–3 mm, proving that GPS technology is capable of monitoring railway subgrade. Xi et al. [8] develops a monitoring platform to detect the deformation of the short baseline in the Plough system, concluding that calculation of the deformation based on 4-h observation best reflects the actual deformation of the monitoring point, which can satisfy the need for highly precise monitoring of different engineering works and geological disaster. So, in this paper, 12-h observation can ensure the accuracy. Hu et al. [9] adopts GPS positioning technique to detect the landslide mass in the permafrost area and analyzes the features of landslide mass at different places. Yang et al. [10] develops an intelligent monitoring system, which can realize long-term monitoring of the strain permafrost status along with temperature changes. The paper also analyzes the changes of permafrost subgrade due to the factors of temperature and depth. Different GPS stations' foundation bed have different temperatures and geological conditions, so GPS stations in this paper are in the same depth to ensure the more conditions for consistency. Ma et al. [11] makes an analysis of the railway subgrade in permafrost region of Qinghai–Tibet railway, discovering that all the subgrade deformation mainly takes the form of sedimentation, and the amount of deformation is closely related to the changes of its underlying geothermal field. The paper explains the relation between the temperature and subgrade deformation in detail. In permafrost region, there is a sizable order of railway subgrade frost heave deformation, which deserves sufficient attention in engineering practice. Especially in the Qinghai–Tibet Plateau and northeast China, there are some monitoring systems, which can succeed monitor the deformation. However, the research about frost heave deformation hasn't involved the deformation changes of a day. The paper establishes a data collection platform to monitor the railway subgrade frost heave deformation in Heilongjiang Province based on GPS and exploits high-precision GPS positioning monitoring software to do data processing. The paper also analyzes the connection between the monitoring effect of GPS system and temperature variation in northeast China region.

2. Data collection and data processing

2.1. Data collection platform

In order to carry out data quality and accuracy assessment of the railway subgrade deformation in high-latitude area in China, this study established five GPS stations on one section of the high-speed train railway in Heilongjiang Province. The five GPS stations formed a deformation monitoring net with the spacing distance ranging from 4.448 m to 237.404 m (The distribution of the stations is shown in Fig. 1). All five stations adopted TRIMBLE NETR9 receiver and CHOKE RING antenna (TRM59900.00). The antenna was fixed on the forced centering foundation bed, which is installed on a horizontal observation pillar. The data were collected from January 1st, 2015 to April 1st, 2015 (111 days in total) with 24-h uninterrupted observation and 15 s sampling interval.

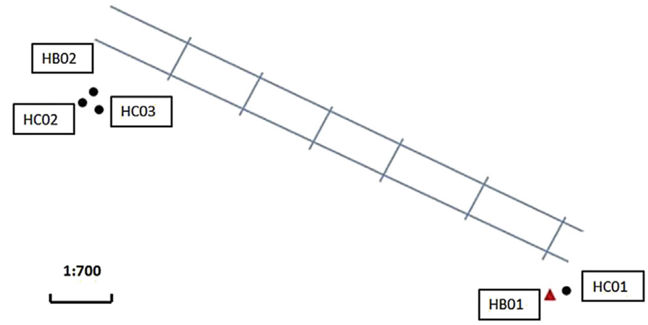

Fig. 1 – Experimental tracking stations.

2.2. Data processing

Based on the short baseline of deformation monitoring and the need for high accuracy, this paper refines GPS baseline solution model and unites the eight International GNSS Service (IGS) stations to do unified calculation by GAMIT software. The main models and the strategies of baseline processing are shown in Table 1.

Ambiguity resolution is a key issue in the high-precision GNSS deformation monitoring. In this software, ambiguity resolution followed a sequential strategy:

a) An independent set of double-difference phase biases are selected according to the baseline length.
b) For each baseline, the satellite with the most observations is selected as reference satellite and forms the DD ambiguities.
c) Form and solve the normal equation to obtain the float solution.
d) All the float ambiguities are sorted by the probability of being fixed to integers and those ambiguities with highest probability are firstly fixed to integers.

Table 1 – Strategies of baselines processing.

Item	Models & constraints
Observation session	24 h
Elevation angle cut-off	15°
Ephemeris	Broadcast ephemeris
Observations	Original L1 carrier phase observations are utilized to estimate all parameters L2 observations are only used for detecting cycle slips
Ionospheric delay correction	Double-difference (DD) model
Tropospheric delay correction	Saastamoinen model and the piecewise linear method is adopted to estimate the residual of troposphere delay effect
Solid Earth tides & ocean tide	IERS2010
Parameter estimation	Network-solution
Integer ambiguity estimation	Decision function + Bootstrap