Study on deformation characteristics of permafrost roadbed considering the influence of temperature field

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Abstract. Taking ha-da railway passenger line as the research object, the temperature field of the subgrade in frozen soil area is simulated by numerical calculation method, and the influencing factors and distribution of the temperature field of the permafrost subgrade are analysed. Finally, the following results are obtained: with the increase of climate warming temperature, the temperature field in the roadbed changes slowly, and the temperature at different depths increases. When the maximum freezing depth appeared after 20 years, the roadbed was in full positive temperature due to the influence of climate warming. The settlement of roadbed after construction under the action of temperature field and force field does not exceed 15mm, which meets the requirements of the code.

1. Introduction
Frozen soil is a soil with extremely strong temperature sensitivity and instability [1-2], and its physical and mechanical properties change dramatically with the thermal disturbance of the external environment [3]. It is very important to study the variation law of subgrade temperature field to solve the road diseases in permafrost region. Uneven melting and sinking deformation of permafrost roadbed has become a common disease in this region, seriously affecting the normal operation and driving safety of roads [1-2]. In view of the stability of permafrost roadbed, extensive studies have been carried out at home and abroad. The water and heat migration and ice formation process of permafrost are essentially the solid, liquid and thermal coupling problems of porous multi-phase media with phase transition. At present, most of the work at home and abroad is still in the stage of experimental exploration [1-3]. Foreign studies from the Angle of different solid-liquid thermal three coupling are studied, and the frost heave, hydrothermal migration and pore caused by water freezing suction research [4-6], but on asphalt pavement embankment in permafrost region of permafrost subgrade is mainly aimed at problems and studies the temperature field of pavement structure layer, the permafrost area fill roadbed subgrade deformation characteristics of temperature distribution under the condition of the study also is less, this paper is based on the municipal engineering, research, provide reference for highway engineering construction in permafrost.
In recent years, with the development of national economy, tourism and national defense, as well as the comprehensive implementation of the strategy of vigorously developing infrastructure, the state has increased investment in railway and highway construction.

Harbin - dalian railway passenger dedicated line is one of the railways with the highest speed under construction in China. It starts from Harbin and ends in dalian and runs through three provinces in northeast China. The line is 903.9km long. The cold region is located in the North-East, with moisture in subgrade soil freeze into ice and ice melting in the permafrost subgrade frost heave and thawing settlement phenomenon, often produce deformation of roadbed and road damage, and the project on line deformation is to ask for "zero settlement", the subgrade filling should not only meet the requirements of high speed railway, more important still need to meet the requirements of antifreeze performance of seasonal frozen soil region. However, the existing engineering experience (including technical standards) can not fully meet the requirements in this regard. Under this situation, it is obviously of great economic significance and social benefits to carry out experimental research on high-speed railway roadbed filling for the Harbin - dalian railway passenger line located in the seasonal frozen soil area.

The research of this topic can not only serve the later roadbed construction, but also provide guidance for similar projects in the future. Therefore, the development of this topic will play a positive role in the development of the railway construction of Harbin and dalian and even the national high-speed railway construction network.

2. Coupling analysis of subgrade

In the seasonal frozen area, the temperature field changes due to the presence of temperature and water, leading to ice-water phase transition in soil, which has a great impact on the mechanical properties of soil. Therefore, it is very necessary to simulate the temperature field of subgrade in seasonal frozen area. In this chapter, the general finite element software ANSYS is used to simulate the variation rule of subgrade temperature field, and the temperature field and deformation field are coupled to analyze the influence of thermal action on subgrade deformation, predict the change of temperature field in subgrade and the deformation trend of subgrade after many years, and put forward the prevention measures timely.

2.1. The boundary conditions

Referring to the actual section form, size and geological data of subgrade in fuyu station test section of tj-3 bid section, the calculation model was established, as shown in figure 1.

![Figure 1. Calculation section model diagram](image)

The embankment height in the figure is 5m, and the transverse distance under the slope is 30m. The original foundation is 20m deep, and the temperature at 20m depth is considered to be basically stable. To eliminate the influence of "boundary layer", the original subgrade section 0.4m below is taken as the upper surface of the calculated subgrade. The top face of embankment is 14.6m wide and the bottom face is 30m wide. From the top to the bottom, the foundation is divided into six layers: gravel layer, A, B material layer, cushion layer, clayey loess, silty clay and medium sand.

2.2. Numerical simulation of subgrade deformation

The settlement requirements of Harbin are strict, and the specific requirements are shown in table1. The frost heave, thaw and subsidence of soil in seasonal frozen area will inevitably cause settlement deformation of roadbed. Therefore, controlling the settlement of roadbed is one of the key problems in
the construction of Harbin. Therefore, it is necessary to use numerical simulation to predict the settlement of subgrade, and the development trend of subgrade settlement can be understood qualitatively through analysis, so as to take effective measures in advance and prevent potential problems.

Table 1. Settlement control values of subgrade after construction

| Post-construction settlement (mm) | Uneven settlement (mm/20m) | Differential settlement (mm) | Angle |
|----------------------------------|---------------------------|----------------------------|-------|
| ≤15                              | ≤20                       | ≤5                         | ≤1/1000 |

The deformation analysis of roadbed under the action of heat is a multi-field coupling analysis, which is a nonlinear problem. It is not only caused by the state change, but also by the material nature, which also increases the difficulty of the analysis. Because the influence of deformation field on temperature field is small, the deformation analysis of embankment is carried out through the unidirectional coupling of temperature field to deformation field.

In the analysis, ANSYS finite element software and 8-node quadrilateral structural element were still used. Then, parameters were input into the structural module, and the calculated results of temperature field were used to calculate the results of deformation field.

2.3. Parameter selection

Elastic modulus is an important physical quantity to evaluate the deformation of frozen soil. In frozen soil mechanics, TRITOVICEH pointed out that, like other soils, the main elastic indexes of homogeneous frozen soil include normal elastic modulus and transverse elastic modulus (poisson's ratio). The normal elastic modulus of frozen soil is related to soil quality, soil temperature, water content and external pressure.

According to relevant studies on relevant data, the values of elastic modulus of each layer of soil at different temperatures in the calculation are shown in table 2.

Table 2 modulus of elasticity at different temperatures (MPa)

| temperature | -10 | -5 | -1 | -0.5 | 0 | 17 |
|-------------|-----|----|----|------|---|----|
| Graded crushed stone | 225 | 110 | 90 | 8 | 8 | 8 |
| A and B | 120 | 70 | 50 | 2.5 | 2.5 | 2.5 |
| Mattress layer | 1150 | 560 | 258 | 3 | 3 | 3 |

Because the foundation is treated by CFG pile, in order to simplify the calculation, it is considered that the original foundation basically has no settlement, and the elastic modulus of the foundation part is set as a large value in the calculation. The applied load is calculated according to the design specification and converted into the evenly distributed longitudinal load of 180kN/m.

3. Results analysis

Considering the construction period, only the gravity stress of soil mass is considered in the construction stage, and then the external load is added in the operation stage.

3.1. settlement

According to the result of temperature field, the deformation field is calculated. During construction, only the influence of temperature field is considered. Therefore, settlement deformation in January and April is shown in figure 2.

It can be seen from figure 2 that the settlement deformation caused by temperature in the construction stage is very small, all of which are several millimeters. The settlement deformation in January is larger than that in April. Considering that the material is expanding and shrinking due to heat, the heat generated when the temperature is high will offset more with gravity, so the settlement will be smaller. Compared with the measured settlement of about 10mm, the reason may be that the
actual rainy season will be experienced and the settlement generated is larger than the calculated one. The actual situation is more complicated. As a simulation method, the development trend of subsidence can be effectively seen, but the actual measured value should prevail.

![Figure 2. Settlement deformation in different months (unit: m)](image)

The deformation field after 20 years is also calculated and simulated. Since the passenger dedicated line has been in operation during this period, the combined influence of load and temperature on the roadbed during the service period of the train is taken into account. Therefore, the settlement deformation in January and April of 2030 is shown in figure 3.

![Figure 3. Settlement deformation in different months (unit: m)](image)

It can be seen from figure 3 that the post-construction settlement during the operation stage does not exceed the requirement of 15mm. The settlement of roadbed in the normal operation stage can meet the requirements of the code, but drainage measures should be taken to ensure smooth drainage to ensure the normal operation of the line.

Meanwhile, it can be seen from figure 2 that the heat generated by the temperature is less than the gravity, which results in a small downward deformation of the embankment part. It also indicates that the subgrade packing has no frost heaving or no obvious frost heaving, and the subgrade packing can meet the requirements under the action of negative temperature in the seasonal freezing area. Figure 3 also shows that the roadbed can meet the requirements after normal operation under the action of temperature for 20 years, without frost heave and other disasters.

3.2. Horizontal displacement

Horizontal displacement is also an important index to evaluate the stability of embankment. Therefore, in this calculation and analysis, the horizontal displacement of roadbed is also simulated. The horizontal displacement of each period is shown in figure 4.

As can be seen from the figure above, the horizontal displacement during the construction period is about 15mm, and the operation period is 24mm ~ 25mm. April was slightly larger than January, indicating that the temperature force had a certain effect on the lateral deformation.
4. Conclusion
From the above numerical analysis, the following conclusions can be drawn:

(1) with the increase of climate warming temperature, the temperature field in the roadbed changes slowly, and the temperature at different depths tends to increase; In the period when the maximum freezing depth appeared after 20 years, due to the influence of climate warming, the roadbed was in a state of full positive temperature, which indicated that the period when the roadbed in the seasonal freezing area was in negative temperature became shorter, and the maximum freezing depth of the roadbed decreased.

(2) according to the numerical simulation results, the settlement of roadbed after construction under the action of temperature field and force field does not exceed 15mm, which meets the requirements of the specification; Roadbed packing did not occur frost heave or frost heave is not obvious, can meet the requirements of seasonal frost area under the action of negative temperature.

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