Simulation analysis of temperature field of permafrost roadbed

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Abstract. The finite element analysis model of roadbed temperature field in permafrost region is established with finite element software platform. By using this model, the temperature field of roadbed is compared and analysed, and the freezing-thawing depth and variation rule of roadbed are studied. The results showed that the actual freezing depth was 1.8m. With the increase of the climate warming temperature, the temperature field in the roadbed changes slowly, and the temperature at different depths increases. Due to the influence of climate warming, the roadbed was in a complete positive temperature state when the maximum freezing depth appeared after 20 years. The result shown that the time of the roadbed appeared in the maximum freezing depth was earlier, the time of the roadbed in the seasonal freezing area became shorter, and the maximum freezing depth decreased.

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. J rgensen et al. [4] studied the cooling effect of improved ventilation and heat dissipation embankment. Kudriavtcev et al. [5] established a finite element model to predict the change of frozen soil upper limit. Ling et al. [6] analyzed the variation rule of the thickness of permafrost non-freezing layer.

This paper analyzes the thermal stability of the subgrade by establishing the temperature field finite element model, and studies the variation rule of subgrade Frozen depth and melting depth, so as to provide theoretical reference for the construction of highways and the selection of effective protection measures for permafrost.

2 Project overview

Haerbin-dalian railway passenger dedicated line is the one of the highest speed of railway construction, the railway lines throughout the three northeastern provinces, the annual average temperature in the location is 4.4 °C to 10.9 °C, extreme maximum temperature is 39.8 °C, extreme minimum temperature can reach -40 °C, the maximum snow thickness is 30 cm, seasonal frozen soil depth can be more than 2 m, the ice in the roadbed will

lead to settlement phenomenon, which often produce deformation of roadbed and road damage, however, The existing engineering experience (including technical standards) cannot fully meet the requirements in this regard. Under this circumstance, the study on the frozen swelling of roadbed in the seasonal frozen soil area has important economic significance and social benefits.

3 Analysis of subgrade temperature variation

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 law of subgrade temperature field, predict the variation of subgrade temperature field and the deformation trend of subgrade after many years, and put forward the preventive measures in time.

3.1 The boundary conditions

Because the surface of roadbed is involved in the integrated heat transfer processes such as solar radiation heat absorption, surface turbulence exchange, evaporation and condensation, etc., it is extremely complicated. Therefore, the surface temperature cannot be used as the upper boundary temperature of roadbed heat conduction calculation, so the "boundary layer principle" is introduced. The thickness of "boundary

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layer" is the depth of soil layer affected by solar radiation day and night. Through theoretical estimation and long-term observation under natural conditions, the theoretical

estimation and measured values of boundary layer thickness are got.

Table 1 theoretical estimation and actual observation of the thickness of the attached surface

Subsurface type	Usually moist subclay	Dry gravel soil	sphalt concrete
Temperature coefficient $\alpha \times 10^3 / (\text{m}^2/\text{h})$	1.0	2.0	2.5
Theoretical estimate /cm	21	30	34
Long-term observations /cm	15	20	35

According to the measured temperature in the test section, the upper boundary condition of roadbed is taken as the geothermal function at a depth of 0.4m below the surface. Based on a lot of studies on permafrost on the qinghai-tibet plateau, the geothermal temperature is generally simulated as a positive metaphysical function.

For the left and right boundary, take the temperature gradient as zero; for the bottom, as the variation range of the ground temperature is very small, it can be taken as a constant. According to the measured data, the ground temperature at a depth of 20m below the ground (bottom boundary) is taken as 2°C.

Before the roadbed is built, the temperature when the roadbed is filled is taken as the initial temperature. In order to achieve the relative stability of the initial temperature condition, the earth temperature several years later was calculated under the above conditions, and the earth temperature at this time was taken as the initial value for the simulation analysis of the temperature field in the next 20 years.

3.2 The section

The height of embankment 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. Reference test section in fuyu station roadbed practical section form, size and geological data, the calculation model is established, the graded crushed stone, A, B, mattress layer, loess, silty clay, medium sand clayey material such as soil temperature, the density, thermal conductivity of soil, soil for the parameters such as enthalpy of determined by experiment, due to space limitations, go here.

3.3 Solving method

The general finite element software ANSYS was used to solve the problem. Because the subgrade is long in longitudinal direction, it belongs to the problem of plane strain, so the quadrilateral 8-node element is used for grid division. The material properties of different soil elements are defined and the boundary conditions are applied on the boundary of the calculated area.

In the calculation, the temperature condition of the original surface boundary was calculated for 2 years with no temperature rise year by year to obtain the initial temperature of each point of soil within the foundation. Then the temperature constraint of the surface boundary was removed, and the temperature boundary of the new boundary after filling the roadbed was increased year by year to apply, and then 20 years were calculated.

3.4 Results analysis

The geothermal curves of the same date in different years are shown in figure 1.

Figure 1 (a) is the temperature distribution map at the end of January, 2011. It can be seen from the field observation data that the end of January is the stage with the maximum ground temperature negative temperature. It can be seen that the surface temperature of the roadbed is low, the lower it is, the higher the heat is transferring upward, and the negative temperature is transferring downward, indicating that although the surface temperature is the lowest, it is not the moment when the freezing depth is maximum. It can be seen from the comparison of (a) and (b) that, with the action of climate warming and temperature cycle, the ground temperature at all depths increased from 2011 to 2030, the temperature field was stable, and the form of the temperature field at all depths remained basically unchanged.

Figure 1 (c) shows the temperature distribution in the middle of April, 2011. It can be seen that although the surface temperature is greater than 0°C, the internal ground temperature still has a negative temperature. At this stage, the negative temperature value is very small and is changing to a positive temperature. At this time, the freezing depth is 1.8m, which is basically close to the measured 1.66m. Figure 1 (d) shows the temperature field in the middle of April 2030. It can be seen that with the alternations of temperature cycle and the effect of climate warming, the temperature field at this stage has been completely in a state of positive temperature, indicating that the freezing time of roadbed is shortened and the maximum freezing depth is reduced.

Figure 1 (a), (b) and (c) all have the rule that the freezing depth of subgrade filler is lower than that of the original foundation, indicating that the filler has good frost resistance, which is also consistent with the measured results.

4 Conclusion

From the above numerical analysis, the following conclusions can be drawn:

- (1) according to the numerical analysis, the simulated actual freezing depth is 1.8m;
- (2) according to the analysis and calculation, With the increase of the climate warming temperature, the temperature field in the roadbed changes slowly, and the temperature at different depths increases. Due to the influence of climate warming, the roadbed was in a complete positive temperature state when the maximum freezing depth appeared after 20 years. The result shown

that the time of the roadbed appeared in the maximum freezing depth was earlier, the time of the roadbed in the seasonal freezing area became shorter, and the maximum freezing depth decreased.

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