Temperature Field Analysis of Electric Tracing for Pavement of Tunnel Portal in Cold-region by FEM

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Abstract

On the basis of the important research on deicing and melting snow by electric tracing of anti-skidding technology for road engineering in cold region, this paper analyzes on temperature field of electric tracing for anti-skidding pavement of tunnel portal in cold region by FEM. Results show that the temperature field calculated with the method in this paper is very approaching to analytic solution of G Comini & C Nonino. Under different outdoor temperatures, pavement temperature could be preheated to 2°C within 4-6 hours with different cable powers, thus the appropriate cable power could realize preheating for deicing and melting snow.

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1. Introduction

Snow and ice on road would seriously affect smooth traffic and driving safety, tunnel portal in cold region in particular. While the currently widely applied deicing and melting chemicals have many negative environmental effects. However, heating cable has the advantages of safe, durable, environmental protection, etc., and excellent compressive property would be achieved when placing electric tracing heating cable in bituminous concrete, thus it is safe and reliable to apply heating cable to deicing and snow melting of road. The paper with background of road deicing and snow melting of Northeast China carries out heat transfer analysis focusing on this problem, establishes mathematical

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model of laying heating cable in pavement concrete targeting at deicing and snow melting, and calculates variation of temperature field of testing item in different climate conditions by FEM, so as to judge the snow melting effect, providing theoretical references to application of this method in practical engineering.

2. Calculating Model

In ANSYS calculation, deal with initial conditions as follows: Under the circumstance not initiating heating cables, calculation shall be done by taking 10h according to boundary conditions. When node temperature variation within unit length is less than 0.05 ℃, it should be deemed that the temperature field is stable. And take the temperature field at this point as the initial temperature point. In calculation, boundary conditions of upper surface are multi load steps; take the calculation for initial temperature as the first load step, then carry out the following load steps on basis of actual conditions.

3. Numerical Analysis and Comparison of Test Results

Take heat cable of 17W/m in indoor test. The cable power is 252W/m2. Load heat flow of 250 W/m2 in numerical simulation analysis, and heat flow on cable surface shall be 816.59 W/m2. According to the test conditions, simulations are done for variations of test item in the temperatures of -5 ℃ and -10 ℃ when heated for 5h and 10h. The indoor temperature field contour line is shown as Fig. 1.

![Temperature Contour Line in the Temperature of -10℃ When Heated for 10h](image)

Comparison of calculation results and experimental data of upper surface temperatures of heating cables after different time under two different outdoor temperatures is shown in Fig. 2. It can be concluded from the figure that calculation results and experimental results of upper surface temperatures are almost the same. Due to restricted experimental conditions, temperature measuring device is only embedded in the center of heating cable on the upper surface, while grid partition of calculation results is thick and there are many nodes, there are a few variations.
To sum up the above comparison, we can see that experiment results are close to calculation results with certain differences. The reasons are: Although time selected for experiment is at night when there are only few temperature variations, the temperature still has some fluctuations of ±0.5℃ during experiment. However, the temperature load during calculation is a steady state value, thus resulting in differences of calculation results and experimental results. Besides, initial temperature inside the structural layer is determined when it is deemed as stable after loading for several hours, which would probably different from the actual initial temperature.

4. Calculated Temperature Field of Structural Layer

Fig. 3 shows the stable temperature field inside the structural layer of pavement after the heating cable has worked for some time. We can see from it that temperature field formed between the neighboring heating cables takes the shape of “saddle”. Within the whole structural layer, the highest temperature lies in outside surface of the heating cable, while the lowest temperature lies in the upper part of the vertical line of upper surface and center of the two cables. On the layer burying the heating cable, temperature gradient is large and the closer to the pavement surface, the less the temperature gradient is. On the pavement surface, temperature field has been relatively uniformly distributed. This result is very close to the analytic solutions drawn by G Comini & C Nonino.

5. Confirmation of Optimum Preheating Time
In order to study on temperature rise of the pavement surface, we imbed temperature measuring facility on surface of the test item during experiment to observe the variation of surface temperature with time changes. Fig. 4 shows the temperature variations of measuring points on the pavement surface when the temperature is -10℃. When indoor temperature is a steady state value, temperature curve of each point should be a convex curve, and pavement surface temperature is rising sharply during the initial time period with rising curve. With proceeding of heat transfer, there will be saved heat in the structural layer, temperature rising shall slow down, temperature field shall develop toward the stable state gradually, as well as the temperature curve shall be gentle.

From field experiment research and simulation calculation of temperature field, it can be concluded that one of the features of deicing and snow melting system of pavement by heating cable is long preheating time, therefore, time required from the start of operation to reaching the design temperature value is also an important parameter for evaluating its performance. In large quantity of simulated numerical analysis, research has been done for temperature rising under different outdoor temperatures and powers. According to the weather forecast, power on several hours before the snow, and the temperature will rise by 2-3℃. Once there is snow, the surface temperature will melt it. According to local weather conditions of the project site, calculate the time required for rising the temperature to 2-3℃ under different outdoor temperatures with recommended cable power. During the experiment, we found that with the same power, preheating time was prolonged with outdoor temperature drop. E.g. when the power is 250W, the upper surface temperature can only reach the standard for about 10h. Moreover, with temperature drop, time required for melting snow will be longer. Such long preheating time has no practical value in practical application. Through detailed survey, comparison and calculation, the most economic and acceptable preheating time is set between 4-6h. For guaranteeing satisfying the requirement for snow melting during this preheating time, different cable powers should be equipped in different temperatures. Therefore, we have carried out a good deal of simulations during calculation and fixed the powers required for reaching the optimum preheating time when the temperature is -5℃, -10℃, -15℃ and -20℃ respectively.
Fig. 5 is the temperature chart and contour map of structural layer of pavement when surface temperature is between 2-10°C with outdoor temperature of -10°C and heating power of 350W, the preheating time is about 4.83h.

From the different temperatures above and the heating effects of different powers, it can be concluded that under different outdoor temperatures, different cable powers can satisfy the requirements of preheating the pavement temperature to 2°C within 4-6h, perfectly realizing the effect of deicing and snow melting by preheating.

Summary

Adopting the fundamental theory of heat transfer and with the help of ANSYS, compared the experiment and simulation of temperature field of structural layer of pavement and upper surface temperature variations with time changes, analyzed the reasons for the differences, and verified the reasonable of calculating model. On this basis, discussed variation trend of pavement surface temperature and analyzed preheating time of pavement surface. After determining the optimum preheating time range, carried out large number of simulation calculations and analyzed the cable power requirements for reaching the standard of deicing and snow melting under different temperatures, thus laid foundation for design and control of the following cable powers.

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