Study on Sensitivity of Horizontal Freezing Parameters of Complex Curtain

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Abstract. During the freezing construction, the temperature field, as a direct controlling variable, is affected by many factors in practical engineering. Therefore, based on the nonlinear finite element software ABAQUS and taking the actual physical parameters as the benchmark, this paper combines with a subway connecting passage project, and uses the single variable control method to analyze the influence of the thermal physical parameters of the soil on the freezing construction period of the soil: thermal conductivity, thermal conductivity, specific heat, latent heat and other thermal physical parameters. The results of this paper provide reliable support for the construction and design of similar projects.

1. Introduction

With the continuous development of urban rail transit in our country, horizontal freezing technology is used more and more widely in underground engineering to isolate groundwater and reinforce unfavorable rock and soil strata. When soil layer freezes, free water freezing and water migration in rock and soil lead to frost heaving of soil. Excessive frost heaving will affect or even destroy underground pipelines, ground buildings, roads, etc. Freezing temperature field is a direct control parameter for freezing construction[1]. Freezing temperature field is affected by many factors[2]. The temperature field theory of artificial frozen soil is one of the basic theories of freezing construction. Scholars in various countries have made in-depth research on the single-row pipe freezing temperature field theory and achieved a series of results[3]. The research and practical engineering application show that the calculation theory of Bachor gold temperature field is the most accurate of all kinds of temperature field theories[4]. However, most of the previous studies only analyzed the applicability and accuracy of the overall calculation results of Babbitt formula, and its applicability was also affected with different freezing forms[5]. Numerical methods have been widely used in simulation of freezing method. In this paper, the influence of thermal physical parameters such as thermal conductivity, thermal conductivity, specific heat and latent heat on the freezing construction period of soil will be studied in combination with practical engineering.
2. Finite Element Model
The selection of soil model size, combined with the engineering practice, the diameter of subway tunnel and the distribution of freezing pipes, takes 50m, 25m and 40m respectively in the three directions of length, width and height.

![Figure 1. Grid division](image)

Since the surface of the soil and the inside of the tunnel need to be in contact with air, it is also necessary to set the thermal conductivity coefficient around the soil and the constant temperature at the bottom boundary of the soil. According to indoor tests, field tests, Tianjin Meteorological Bureau and relevant geological data, the calculation parameters used for finite element are shown in Table 1.

![Figure 1. Grid division](image)

| Temperature (°C) | Thermal conductivity (W/m²·°C) | Specific heat (J/kg·°C) | Density (kg/m³) |
|-----------------|-------------------------------|--------------------------|----------------|
| -10             | 2.22                          | 1022                     | 1840           |
| -2              | 2.1                           | 1080                     | 1883           |
| -1              | 1.54                          | 1330                     | 1320           |
| 10              | 1.44                          | 1453                     | 1364           |

In this model, the thermal conductivity, specific heat and density are considered to change with temperature. In addition, the finite element software ABAQUS also needs to give the latent heat of phase change, solid phase temperature and liquid phase temperature of the excavated body. In this model, the latent heat of soil phase change is 1.07e8J/m³, the solid phase temperature is -2°C and the liquid phase temperature is -1°C.

3. Calculation results

3.1. Study on the Influence Law of Thermal Conductivity on Temperature Field
Definition of thermal conductivity: ratio of heat flux density to temperature gradient. That is, the heat flow density generated in an object under the action of a unit temperature gradient, in W/(m·°C).

Thermal conductivity refers to the heat transferred through an area of 1 square meter within 1 second for a 1m thick material with a temperature difference of 1°C on both sides under stable heat transfer conditions, and is generally expressed by λ.

Assuming that the soil has the same physical parameters except thermal conductivity, the boundary conditions and initial initial conditions of the temperature field are the same.
As shown in Figure 2, the greater the thermal conductivity of the soil, the longer the freezing time of the soil, and the thicker the design freezing curtain, the longer the freezing time required.

3.2. Study on the Influence of Density on Temperature Field
Assuming that the density of the soil changes when all other conditions remain unchanged, the temperature field in the soil changes with the density.

The greater the density of the soil, the longer the time required for the soil to freeze. The thicker the design freezing curtain, the longer the freezing time required.

3.3. Effect of Latent Heat on Temperature Field
Latent heat, short for latent heat of phase change, refers to the amount of heat absorbed or released by a unit mass of matter from one phase to another under isothermal and isobaric conditions. This is one of the characteristics of objects when they transform between solid, liquid and gas phases and between different solid phases. The latent heat between solid and liquid is called heat of fusion (or heat of solidification), the heat of vaporization (or heat of condensation) between liquid and gas, and the heat of sublimation (or heat of sublimation) between solid and gas. The latent heat of phase change of frozen soil shows that when the soil reaches the freezing temperature, the temperature continuously decreases, but when it decreases to a certain temperature, the temperature of the soil will rise again. This is the phenomenon that the soil undergoes phase change and releases heat so that the temperature of the soil will not rise back. When other conditions remain unchanged and only latent heat changes, the freezing time is calculated. The greater the latent heat of the soil, the longer the freezing time of the soil. The thicker the design freezing curtain, the longer the freezing time required.

3.4. Influence Law of Phase Transformation Temperature on Temperature Field
Because the soil contains salts and other minerals, the freezing temperature of the soil in the freezing process is different. Moreover, in the process of water in saline soil changing from liquid state to solid state, phase change will occur, and soil with different phase change temperatures will also be different.

In the following, the influence of phase transition temperature on temperature field will be studied.

Assuming that all other parameters of the soil are unchanged except for the phase change temperature, when the phase change temperature changes, the temperature of each point in the extraction model is extracted, the average temperature of frozen soil curtain with different thickness changes with time is extracted. The phase change temperature of the soil has little effect on the freezing time. The thicker the design freezing curtain, the longer the freezing time required.
3.5. Effect of Specific Heat on Temperature Field

Specific heat capacity is the amount of heat required for a substance with a unit mass to rise to a unit temperature, and represents the physical quantity of an object's heat absorption (or heat dissipation) capability.

\[ Q = CM\Delta t \]

Where \( q \) is the absorbed heat; \( M \) is the mass of the object, and \( t \) is the value of the temperature rising (falling) after absorbing heat (releasing heat).

In the calculation of soil temperature field, soil specific heat capacity is a very important parameter. The following will study the effect of soil specific heat on temperature field. It is assumed that all parameters except specific heat of soil are unchanged, only specific heat changes.

The temperature of each point in the extraction model is extracted, the average temperature of frozen soil curtain with different thickness is extracted with the change value of time, the greater the specific heat of the soil, the longer the freezing time of the soil. The thicker the design freezing curtain, the longer the freezing time required.

4. Conclusion

In this paper, the thermal conductivity of different values are first taken and calculated numerically respectively, and the curves of the average temperature of the frozen curtain with time are obtained under different design thickness values, and the different freezing time curves under different thermal conductivity coefficients are obtained. The curves show that the larger the thermal conductivity coefficient of the soil is, the longer the freezing time is required under a certain design freezing thickness. When the thermal conductivity of soil is constant, the thicker the design freezing curtain is, the longer the freezing time is required.

Then, the influences of various parameters of the soil, such as density, specific heat, latent heat, phase transition temperature of the soil and coefficient of thermal conductivity, on the temperature field are calculated in detail, and the following laws are obtained by plotting the curves.

1. The parameters that have great influence on the temperature field include density, specific heat and thermal conductivity, and their relationship with freezing time is: the larger these three coefficients are, the longer the freezing time is required.

2. Latent heat, phase change temperature of soil, coefficient of thermal conductivity and surface have little effect on freezing time.

3. Different surface temperatures represent different seasons, that is to say, construction in different seasons has little influence on the frozen construction period. However, the latent heat and phase change temperature of the soil have little influence on the construction period, which can reduce the number of tests during the freezing parameter determination period, i.e. save time, save engineering funds and have good economic benefits. However, density, specific heat and thermal conductivity have a great influence on the construction period. In order to accurately guide the design of designers, detailed tests are required to determine their values in the test process.

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