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Original Research Article

Numeirical Simulation for Temperature Field of Freezing Method Construction in Zhengzhou Urban Rail Transit

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Abstract: Taking the undisturbed soil from Zhongyi Road Station ~ CBD Station in Zhengzhou City Rail Transit Line 5 as the object, this paper introduces the basic process of using ANSYS to create a freezing wall temperature field model. The two-dimensional finite element method is used to simulate the formation process of the single-tube temperature field in the horizontal freezing tube. The temperature field of freezing process is studied, and the variation rule of temperature field is provided for the practical engineering construction.

Keywords: Rail traffic construction; Freezing method; Finite element; Temperature field

In recent years, refrigeration technology has been continuously developed and improved, and artificial freezing technology [1] has been increasingly used in the excavation and support of underground communication channels. The freezing method uses artificial refrigeration technology to reduce the temperature of the soil. When the temperature of the water in the soil drops below the freezing point, the soil in the stratum freezes [2] to form a frozen wall. The formation of the frozen wall plays a role in isolating the groundwater and can achieve the purpose of enhancing the strength and stability of the soil [3]. The study of temperature field is an important part of the study of frozen soil. The freezing temperature field is an unstable heat conduction problem with phase change, internal heat source and moving boundary [4-6]. At present, experts and scholars have done a lot of theoretical research on frozen soil [7-8], among which the numerical simulation method has played an important role in the research and application of artificial frozen soil. In this paper, the two-dimensional finite element method is used to simulate the formation process of the freezing temperature field of the horizontal freezing pipe, and the undisturbed soil in the interval between Zhongyi Road Station and CBD Station of Zhengzhou Rail Transit Line 5 Project is used to study the temperature field change law of the freezing method construction process. , Provide theoretical reference for actual engineering construction.

1. Project overview

Zhengzhou Rail Transit Line 5 Project Zhongyi Road Station ~ CBD Station section, starting from the east end of Zhongyi Road Station, along the commercial outer ring road to the east and north, and ending at the west end of the CBD station. The mileage range is: the left line of the section is from left DK9+490.474 to left DK10+449.979, and the length is 983.011 m. Two horizontal curves are set on the left line of the interval positive line, with radii of 540 m and 400 m, respectively; and two flat curves are set on the right line of the interval positive line, with radii of 500 m and 400 m, respectively. The longitudinal slope of the line is designed as a V-shaped energy-saving slope, the maximum slope is 27‰, the minimum slope is 2‰, the ground elevation of the section is about 88.85～89.73 m, and the buried depth of the shield tunnel is about 11.9～23.3 m. The section line is laid along the commercial outer ring road, and the area above the line is mainly municipal roads, and the buildings on both sides of the road are mostly commercial buildings. In the section, a communication channel is set at the right DK10+041.975, which is jointly built with the pump room. This section crosses the Ruyi River from the right DK10+089.409 to the right DK10+207.181 section. The bottom elevation of the Ruyi River is 82.8 m, the deepest water level is 3.5 m, and the rest of the terrain is generally flat. The landform unit in this section is the Yellow River alluvial-proluvial plain (Area). The tunnel structure is mainly located in the silty clay layer, the clay silt layer and the fine sand layer. The track bed type and track structure height of the shield tunnel belong to the general damping section, and the track structure height of the entire section is 760 mm.

2. Freezing plan

The freezing method construction of the connecting passage adopts low-carbon steel seamless steel pipe as the freezing pipe. According to the length and structure of the connecting passage and the thickness and strength of the designed freezing wall, the construction plan of the freezing hole adopts the horizontal freezing method in the single-row pipe hole of the main section of the passage. The construction team drilled in from both ends of the tunnel. The main technical indicators of freezing method construction are: the effective thickness of the freezing curtain is not less than 2.0 m; the freezing cycle time is 30 d; the freezing salt water

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temperature is -20 ℃-30 ℃; the average temperature of the freezing curtain is -10℃; the permeability coefficient is less than 1.0× 10-8 cm/s. The freezing construction drawing of the connecting passage is shown in Figure 1.

3. Finite element model

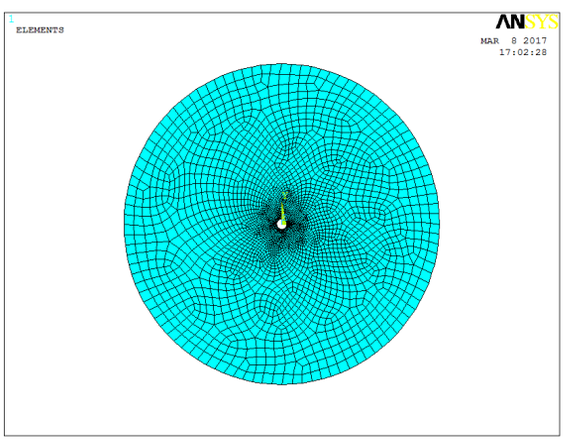
According to the actual operating conditions of the Zhongyi Road Station to the CBD Station of Zhengzhou Rail Transit Line 5 project, a numerical model was established, and the freezing temperature field was simplified into a plane model for analysis

(1) Define the type and material properties of the unit. Enter the Preprocessor | Element Type | Add/Edit/Delete command in ANSYS, the Element Types dialog box appears, click the Add button, and select the Thermal Solid and Quad 4node 55 planar four-node elements in the Library of Element Types two list boxes. Then define the basic thermophysical parameters of the material under the menu Material Props, see Table 1.

Table 1 Basic thermophysical parameter table of soil

state	temperature/℃	Density /(kg•m^{-3})	Heat conduction /(kJ•(m^3•h•℃)$^{-1}$)	Specific heat /(kJ•(mg•℃)$^{-1}$)	Enthalpy/(kJ•m^{-3})
Unfrozen soil	0	1 900	5.233	1.41	250 930
	10	1 900	5.233	1.41	180 537
Frozen soil	-10	1 520	7.645	1.15	0
	-0.2	1 520	7.645	1.15	55 350

(2) Mesh generation. First generate the Area, and then create a freezing tube on the Area. The diameter of the freezing tube is 0.16 m. Enter Preprocessor | Modeling | Operate | Booleans | Subtract, subtract the area of the freezing tube from the large Area, and then divide it by Mesh. In order to improve the calculation accuracy, the closer to the freezing tube, the smaller the unit; the unit farther from the freezing tube should be larger. According to the influence range of the freezing tube freezing, the calculation model adopted when the single tube is frozen is a circular area with a radius of 5.0 m, and the diameter of the freezing tube is 160 mm. The meshing model of the single freezing pipe model is shown in Figure 2 below. The calculation model used when the double pipe is frozen is a rectangular area of 8.0 m×6.0 m, the diameter of the freezing pipe is 160 mm, and the distance between the centers of the two freezing pipes is 1.5 m. The calculation boundary conditions and calculation parameters of the model are the same as those of a single The freeze tube model is the same. The meshing model of the double freezing pipe model is shown in Figure 3 below.



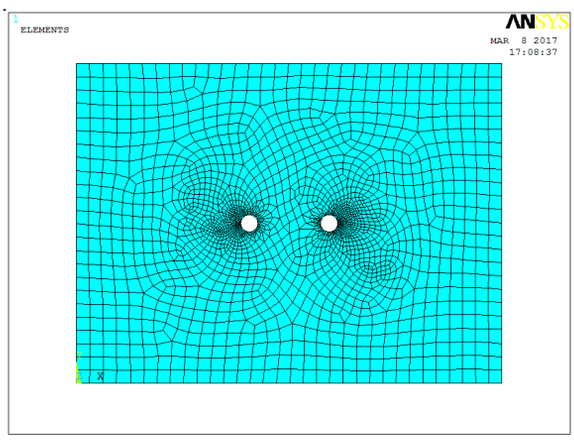


Figure 2 Meshing model of single freezing pipe model

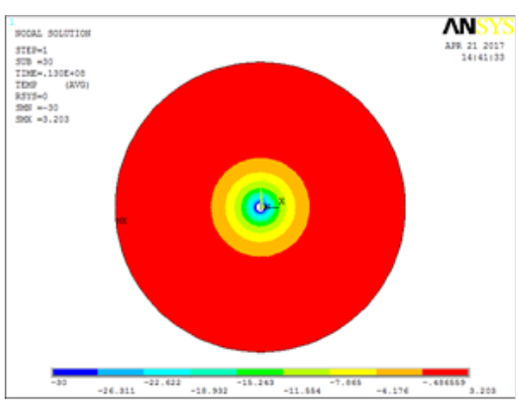
Figure 3 Meshing model of the double freezing pipe model

(3) Boundary conditions. The temperature field is simplified into a plane model for calculation. Taking into account the specific conditions of the actual construction process, the initial temperature of the soil is 10℃, the freezing temperature of the freezing pipe is -30℃, the freezing temperature of the soil is -0.2℃, and the tunnel The surrounding area of is assumed to be an adiabatic boundary, the freezing time of the freezing tube is 150 d, and the time step calculated by the model is 24 h.

4. Temperature field analysis

4.1 Calculation results and analysis of single freezing pipe

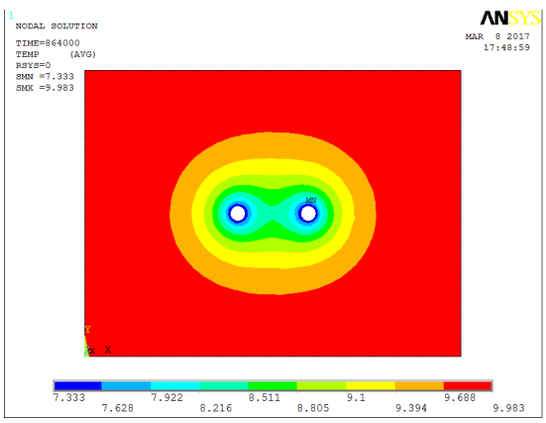
The contour map of the temperature distribution when the freezing temperature field of the single freezing tube is frozen for 150 d is shown in Fig. 4.



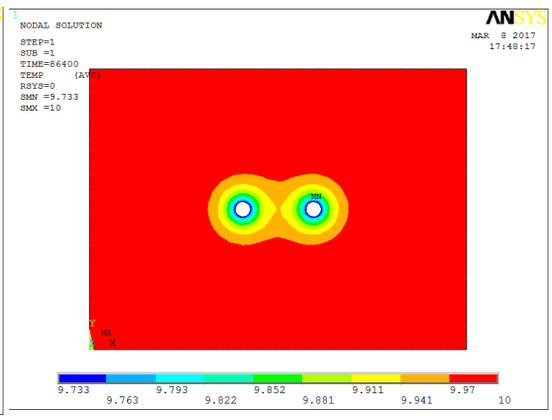
From the analysis of Figure 4, it can be seen that the temperature of the soil gradually decreases with the increase of freezing time. The temperature distribution of the temperature field is a series of concentric circles formed by the freezing tube as the center, and a freezing column is formed around the freezing tube. The closer the temperature of the soil is to the freezing pipe, the lower the temperature; the farther the soil is from the freezing pipe, the higher the temperature. When the freezing time reaches 150d, the temperature of the soil is lower the closer to the freezing tube, the lowest is -30℃; the farther away from the freezing tube, the higher the temperature. It can be seen that the freezing law conforms to the theory of heat conduction of freezing tube temperature.

4.2 Calculation results and analysis of double freezing pipes

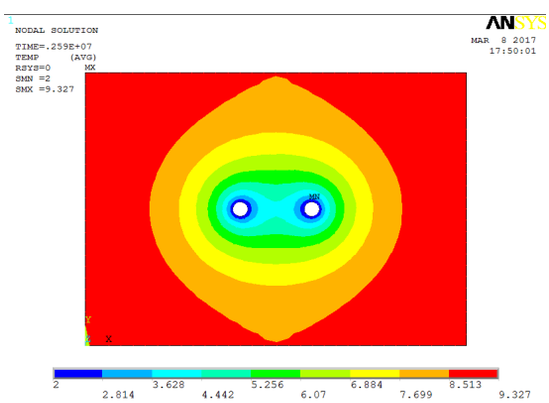
When the double tube is frozen, take active freezing for 150 d. The contour map of the temperature distribution at different times during the freezing process is shown in Figure 6.



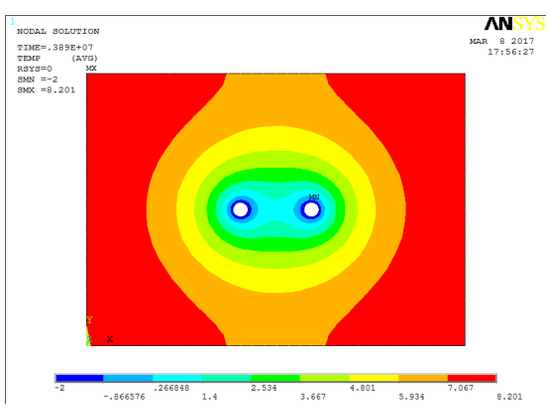
(a) Freeze for 1 d



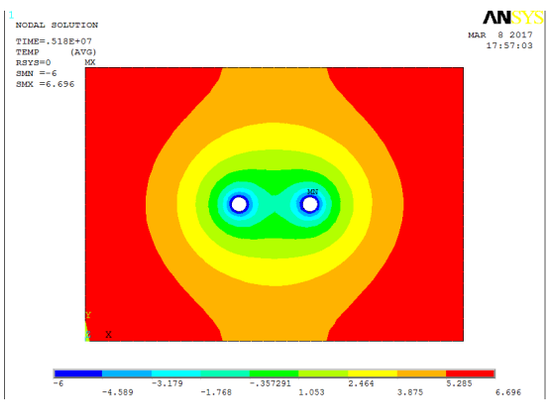
(b) Freeze for 10 d



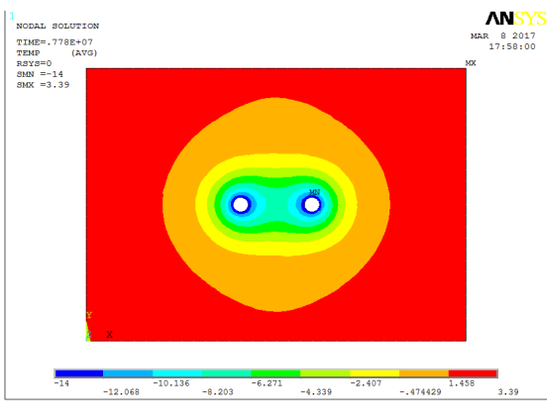
(c) Freeze for 30 d



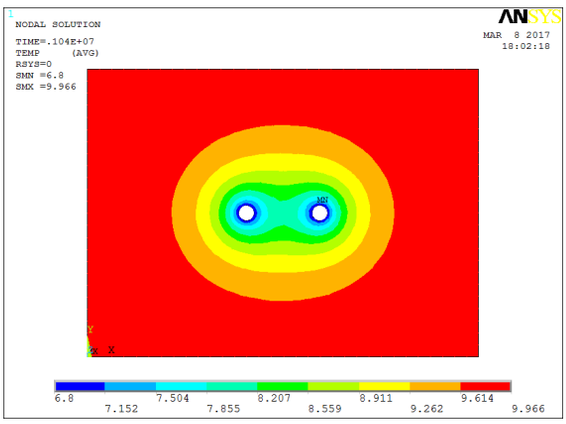
(d) Freeze for 45 d



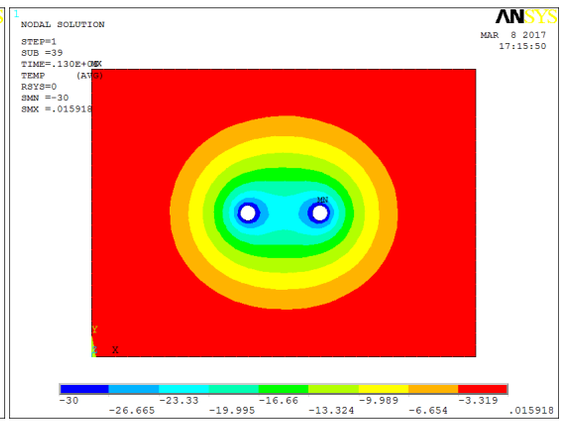
(e) Freeze for 60 d



(f) Freeze for 90 d



(g) Freeze for 120 d



(h) Freeze for 150 d

Analyzing Figure 6 shows that when the double pipes are frozen, the distribution of the temperature field in the soil is not a simple numerical superposition, but shows different characteristics from the single pipe freezing:

(1) Analyzed from the contour temperature cloud map of the temperature field, under the effect of double pipe freezing, the temperature of the soil at the same distance from the freezing pipe during the freezing process is lower than the temperature value of the non-intersecting part. It can be seen from Figures (d) and (e) that the soil temperature in the intersecting part of the initial freezing period drops quickly; Figures (f), (g), and (h) show that the temperature in the soil during the later period of freezing The distribution of is no longer the distribution of a series of concentric circles with the freezing tube as the center, nor is it a simple intersection between two concentric circles, but has evolved into a relatively complex elliptical distribution. At the same time, it is not difficult to see that even in the non-intersectioned part of the soil, the temperature value under the effect of double pipe freezing is lower than that under the same condition of single pipe freezing. Therefore, the author feels that the previous scholars calculated the temperature value of the soil without the intersection to perform simple superposition calculations based on the tangent method, which is a relatively conservative calculation method.

(2) In the later period of freezing, the temperature of the intersection part is horizontally distributed. The closer the distance to the freezing tube, the lower the temperature of the soil. However, its freezing effect is better than that of a single freezing tube. Therefore, in the actual construction process, if some parts need to be frozen, it is very advantageous to use double or multiple rows of freezing pipes for freezing.

5. Conclusion

In this paper, the finite element method is used to simulate the temperature field formation process when single and double pipes are frozen, and the undisturbed soil between Zhongyi Road Station and CBD Station of Zhengzhou Rail Transit Line 5 Project is used as the object to study the temperature field changes during the freezing method construction process. law.

When a single tube is frozen, the temperature distribution of the temperature field is a series of concentric circles formed by the freezing tube as the center, and a freezing column is formed around the freezing tube. The freezing law conforms to the freezing tube temperature heat conduction theory. When the double pipe is frozen, the temperature distribution in the soil presents different characteristics from that when the single pipe is frozen, and it evolves into a relatively complex elliptical distribution. The effect of double-tube freezing is better than that of single-tube freezing. Therefore, in the actual construction process, if some parts need to be frozen, double or multiple rows of freezing pipes should be used for freezing.

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