Study on the influence of horizontal freezing and melting of complex curtain on surrounding environment

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Abstract. In this paper, the 3-D finite element model is used to systematically analyze the displacement field of artificial frozen soil thawing settlement. During the simulation process, the thermophysical parameters change with temperature, such as elastic modulus, density, specific heat and other parameters change with temperature. When calculating the temperature field of melting and settling, the temperature field on which the mechanical parameters are based is given point by point through the field variables. After changing with time, the temperature field changes with the points, and the mechanical parameters also change point by point. To ensure that the simulated melting and settling calculation process is more in line with the actual project. The calculation results of melting and sinking show that the whole displacement field presents nonlinear changes with time and space. The research results of this paper provide reference for the control measures of melting and settling.

1. Introduction
When the frozen soil melts, the ice in the soil melts into water, which will cause thawing deformation under the action of gravity and overlying load. Since the 1930s, many scholars, especially those from the former Soviet Union, have begun to study the settlement of frozen soil during melting. For example, Lapchin proposed to divide the melting settlement of frozen soil into two parts according to the experiment in Norilsk: "Standard melting settlement" (the settlement caused by melting and the constant compression settlement under a certain pressure) and "Variable compression settlement" (the compression settlement increased in proportion to the overlying pressure): Fedorkovsky proposed the most calculation method of saturated clay melting settlement according to the relationship between water content and pressure of cohesive soil[1-2]; Gorishten studied the compressibility of frozen soil during loading and unloading. Tretovich studied the thawing and sinking of frozen soil under load. At present, most of the research results are the relationship between the thawing settlement coefficient of frozen soil and the compression coefficient of melted soil under one-dimensional condition and the particle size composition, moisture content and dry bulk density of the soil, which can be used to calculate the thawing settlement of frozen soil and predict the foundation settlement of normal melted soil[3-4]. However, these formulas are only applicable to the one-dimensional problem of natural frozen soil and are not suitable for the thawing settlement calculation of artificial frozen soil.
Nixon et al. have established a one-dimensional melting model with variable boundary conditions, which can be used to predict melting under one-dimensional conditions\[5-6\]. Foriero et al. used the large strain-based thaw settlement consolidation model for finite element simulation, extended the classical concept of small strain to the large strain theory, based on the dimensionless change of the finite strain thaw settlement consolidation theory proposed by Gibsonetal. considering the change of permeability and compression coefficient during consolidation, predicted the thaw settlement with the dimensionless design table generated by finite element\[7-8\]. Sally Shoop and others used cap model to simulate the deformation of normal melting soil under subgrade load. Material parameters were applied to Drucker-Prager plastic hardening model and ABAQUS finite element software was used for numerical simulation.

In this paper, numerical simulation is used to simulate the artificial freezing and thawing settlement of a subway connecting passage, which has strong adaptability.

2. Theory
When the temperature of frozen stratum rises, frozen soil will melt, and ice crystals in frozen soil will melt into water, reducing the volume by 9%; In addition, after the ice at the contact point of the particles melts, the degree of cementation between the ice and the inclusion of soil particles is reduced, part of the upper acting force originally borne by the inclusion is transferred to the soil skeleton, increasing the effective stress acting on the soil skeleton, while unfrozen water generated in the process reduces the friction between the soil particles, and the structure of the soil particles is easy to adjust. Under the action of self-weight stress, pores in the soil body will be compressed, the volume of the soil body will be reduced, and melting and sedimentation will occur. The settlement of frozen soil after melting consists of two parts: melting settlement and compression settlement, which are respectively expressed by melting settlement coefficient and melting compression coefficient. The magnitude of the thaw settlement coefficient has nothing to do with the pressure but only with the properties of the soil itself and freeze-thaw conditions. It is the main index to measure the thaw settlement characteristics of the soil. Its calculation formula is:

\[
\alpha_0 = \frac{\Delta h_0}{h_0} \times 100\%
\]  

Where: \(\alpha_0\)-coefficient of thawing settlement of frozen soil, %; \(\Delta h_0\) thaw settlement of frozen soil, unit mm; \(h_0\) thaw settlement of frozen soil, unit mm;

Practice has proved that the coefficient of thawing settlement is closely related to the frost heaving rate. If the frost heaving is large, the thawing settlement is large, and the soil layer without frost heaving basically does not occur.

3. Finite Element Model
For stress and displacement analysis, 3D Stress element type shall be adopted, as shown in figure 1.

Figure 1. Finite element model.
3.1. Model Parameters

The frost heaving displacement model is mainly simulated by elastic model, and the element type is C3D8. The required calculation parameters and values are shown in Table 1 below.

| Temperature | Density   | Modulus    | Poisson's Ratio | Expansion Coefficient |
|-------------|-----------|------------|-----------------|-----------------------|
| -10℃        | 1840 kg/m³ | 1.3E+08 pa | 0.25            | -0.033                |
| -2℃         | 1883 kg/m³ | 1.05E+08 pa | 0.28            | -0.021                |
| -1℃         | 1320 kg/m³ | 20000000 pa | 0.32            | -0.002                |
| 10℃         | 1364 kg/m³ | 33200000 pa | 0.34            | 0                     |

Load and boundary conditions, the load is mainly gravity load in soil; The boundary conditions are the complete constraint on the bottom, the constraint on the corresponding directions on the four sides, and the complete constraint on the subway tunnel.

The finite element simulation frozen soil melting model is similar to the frost heaving model, but the initial temperature field of the melting temperature field needs to be used, as shown in figure 2(a), and the melting termination temperature field, as shown in figure 2(b).

4. Calculation results

The finite element analysis results as follows:
As can be seen from the curve in figure 5, in the middle of the freezing curtain surrounded by freezing pipes, i.e. where the excavated connecting passage is located, the displacement of the soil is very small after melting and sinking. The melting and sinking displacement at the frozen curtain is the largest.

An analysis of the curves of figs. 7 and 9 shows that the lowest melting point is the surface directly above the freezing pipe. as it moves away from this central zone, the melting range expands, but the melting displacement also decreases.
5. Conclusion
The process of soil melting is accompanied by soil settlement and changes the stress field in the original state of the soil. When there are buildings around the freezing construction and the maximum displacement of soil thawing settlement is limited, it is necessary to control the thawing settlement range and amount of soil thawing settlement to ensure that the freezing construction will not have destructive influence on the surroundings after it is completed. The problem of thaw settlement displacement is a thermal stress problem. A three-dimensional model is adopted to simulate the thaw settlement displacement field of the connecting channel. The displacement field is highly nonlinear with the change of spatial position and time. The numerical simulation method has high universality and wide adaptability. The results can provide basis for taking measures to control melting and settling.

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