A 3D Thermal Model for Prediction Temperature Field During Artificial Ground Freezing

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Introduction: It's very important to study the heat conduction close to the subway segment. Because of the heat conduction, the length of freezing wall close to segment is less than design value in many cross-passage tunnel projects. At the end, it caused many geotechnical problems. In this work, it has a primary exploration and application on COMSOL Multiphysics, based on the model of heat transfer in soils.

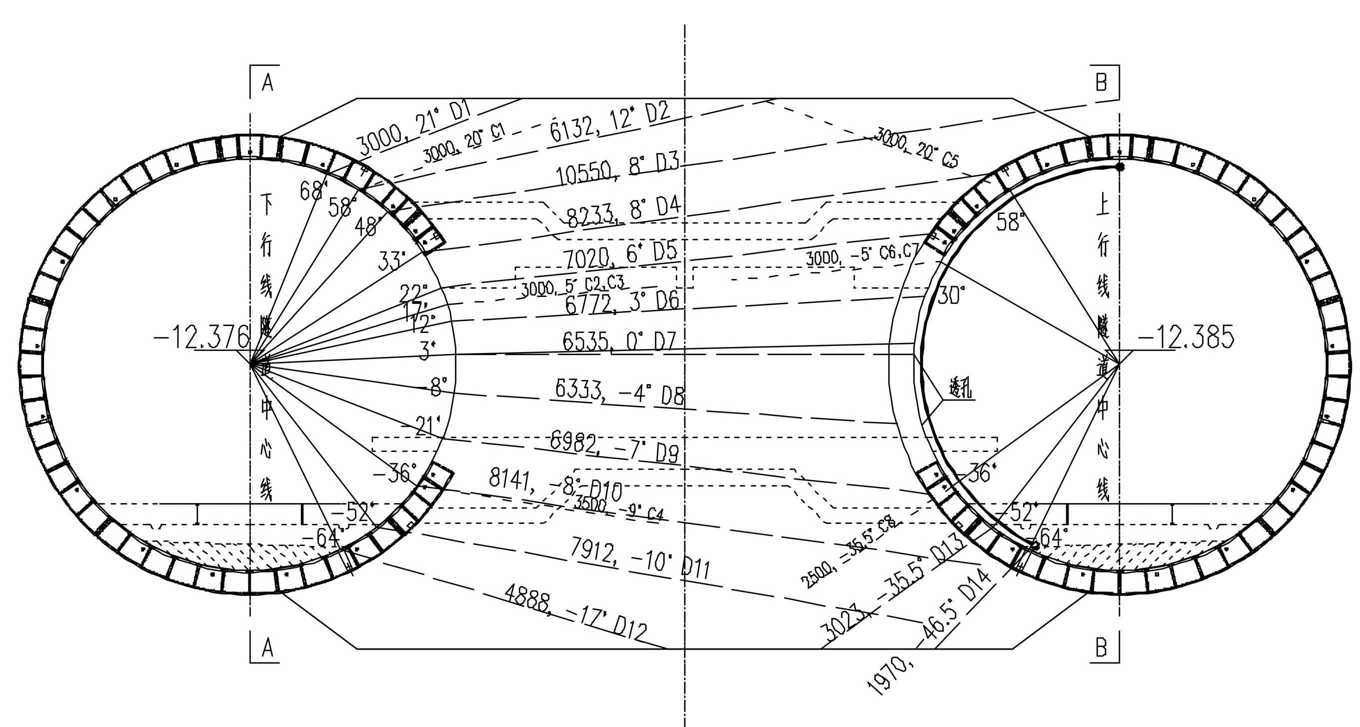

Fig.1 Freeze Pipe Layout of The Cross-passage

Computational Methods: In order to obtain the temperature field in different conditions, it make a 3D Thermal Model shown in Figure.2.

It defined the heat transfer of segment by convective heat flux and the heat transfer coefficient option chose External natural convection. In order to simulate the boundary, it defined an infinite element domain around the model. All temperature parameters were obtained by in-situ observation values. The material properties shown in Table.1.

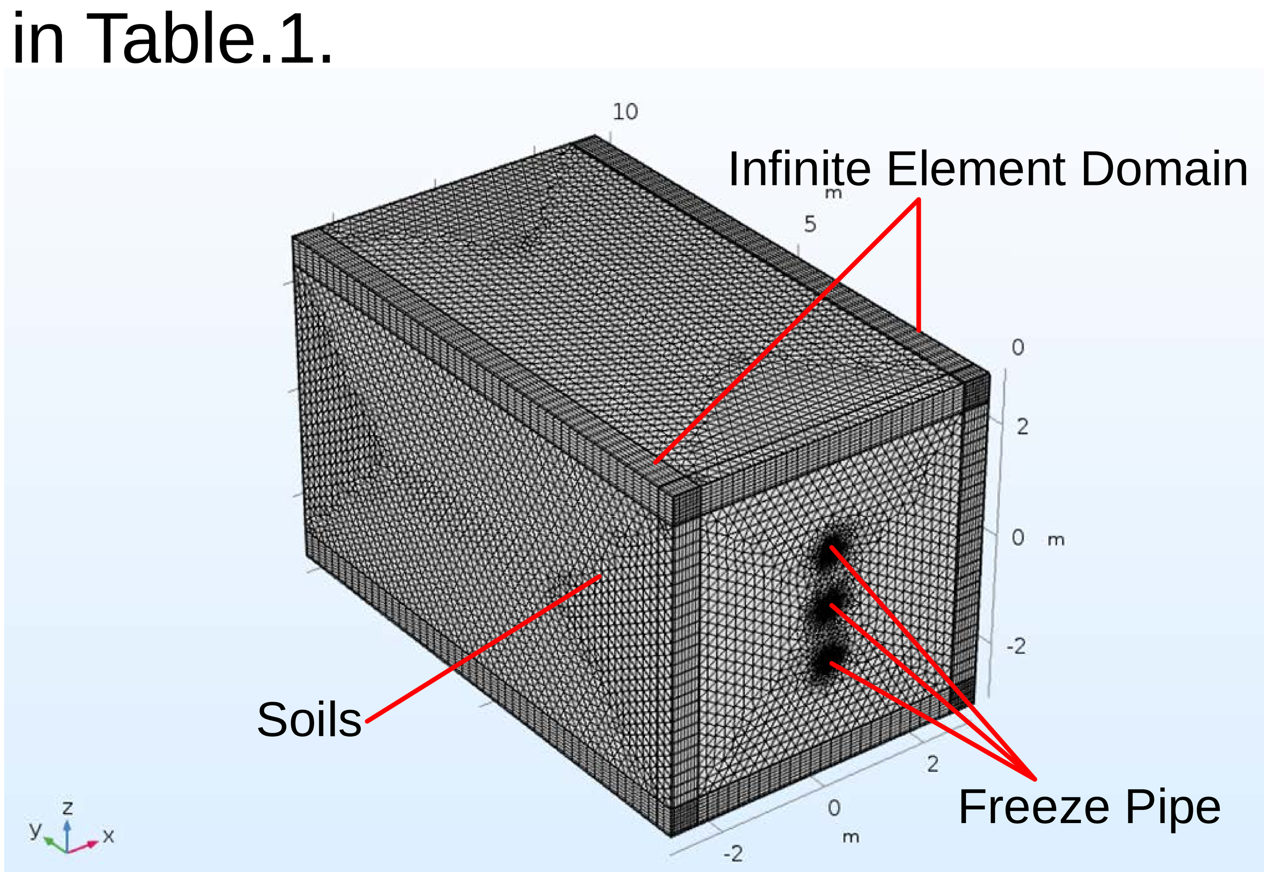

Fig.2 Finite Element Model

Table.1 material properties

Material	Thermal conductivity W/(m•K)	Specific heat J/(kg•K)	Density kg/m³
soil	1.4	1300	1364
Frozen soil	2.1	1022	1840
Concrete	1.8	880	2300
Thermal insulation material	0.03	540	560

Governing Equations:

$$C_{eq} \cdot \frac{\partial T}{\partial t} - \nabla(k_{eq} \cdot \nabla T) + L_i \cdot \rho_w \cdot \Delta\omega_i = Q_G$$

$$Q_G = k' \cdot (T_a - T_s) \cdot A$$

Result: Base on the data of simulation, the influence of heat conduction is very important for the temperature field close to segment. the influence range is more than 2.2m. We get a function of influence coefficient with thermal insulation layer:

$$\eta(x, t) = 1 - \frac{\xi(x, t)}{\xi_{max}(t)}$$

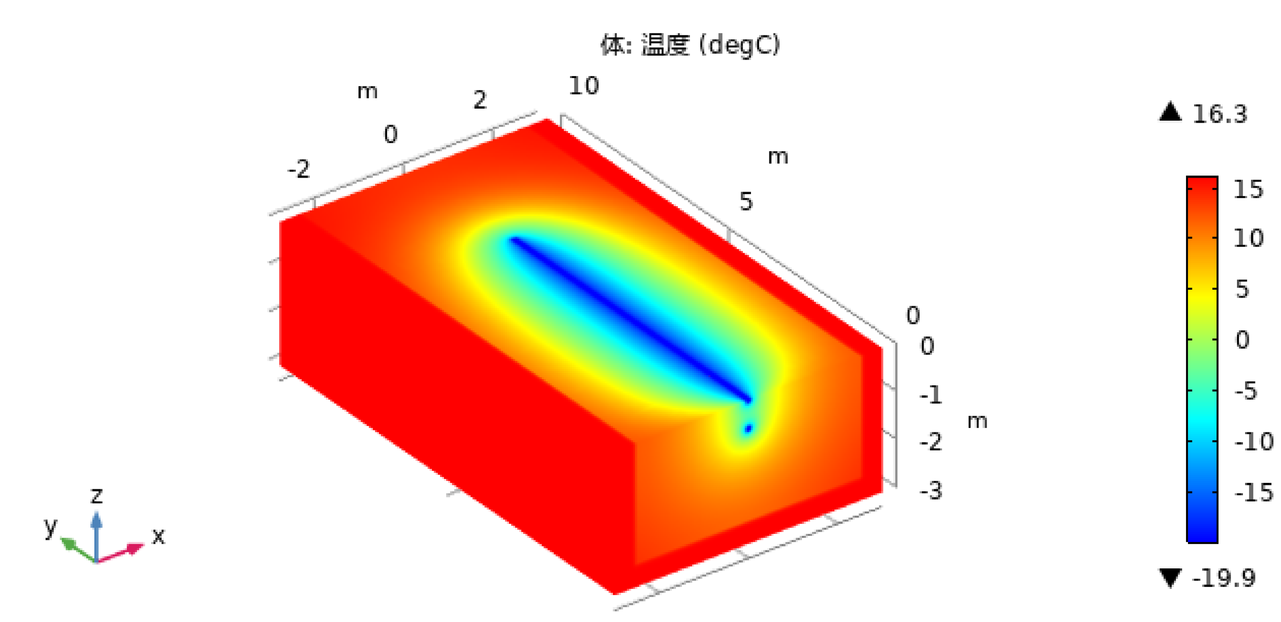

Fig.3 The Temperature Field with Thermal Insulation Layer

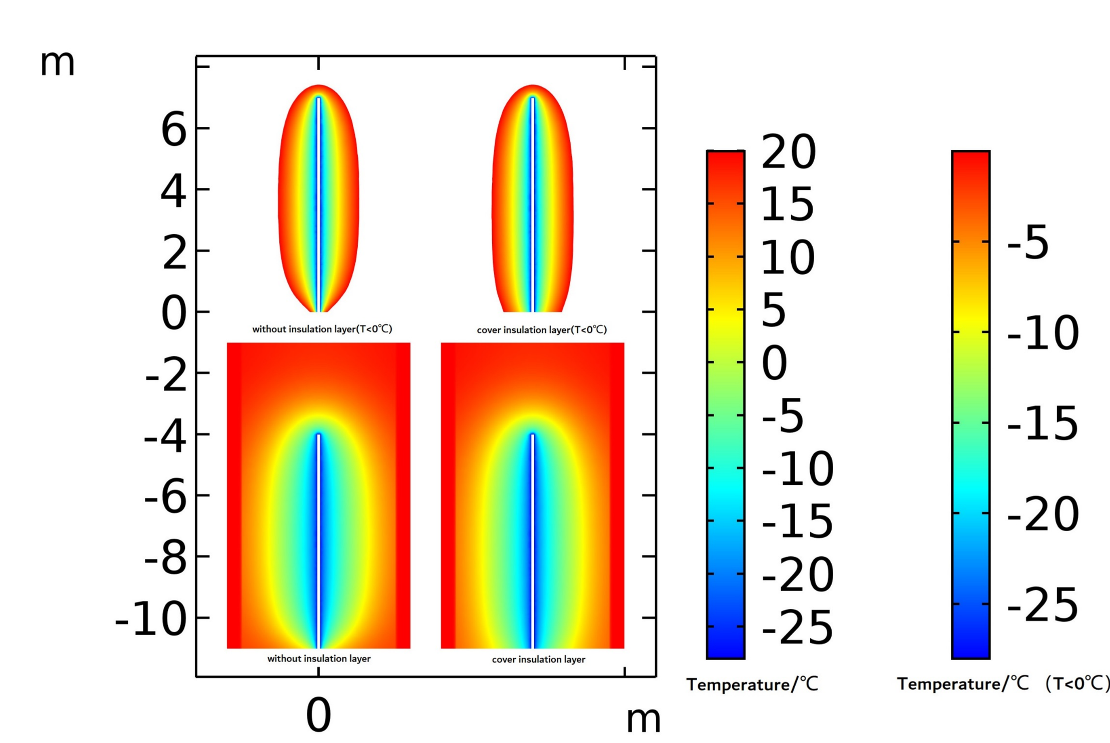

Fig.4 Temperature in Different Condition

Conclusion:

1. The influence of heat dissipation is more than 2.2m
2. Compared with different condition, the thermal insulation layer(5cm, 0.03W/㎡) can reduce more than 50% heat dissipation.

Reference：

1. R. Hu, Q. Liu, Simulation of Heat Transfer during Artificial Ground Freezing Combined with Groundwater Flow, Excerpt from the Proceedings of the 2016 COMSOL Conference in Munich
2. Xiangdong Hu, Fei Zhao, Influence of Heat Dissipation of Main Tunnel Structure on Freezing Effect in Cross Passage Construction. Chinese Journal of Rock Mechanics and Engineering. 2009,28.