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## **Mathematical models of steady-state temperature fields produced by multi-piped freezing**

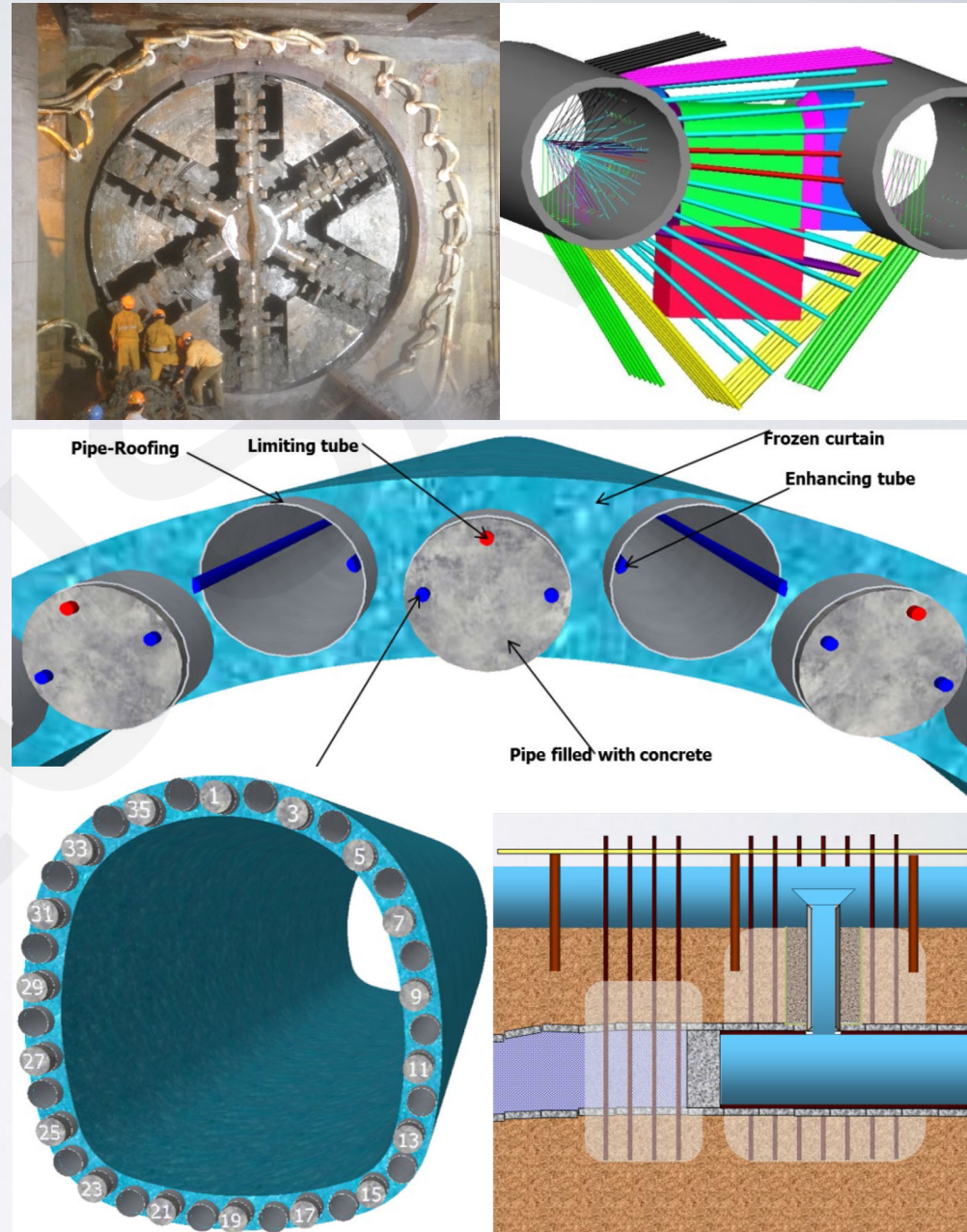
Key words:

Artificial ground freezing (AGF), Multi-piped freezing, Steady state, Temperature field, Analytical solution, Potential function

# What is Artificial Ground Freezing?

➤ A construction method that converts the water in the ground into ice by means of artificial refrigeration technology.

➤ Widely applied in various construction projects.



# Theoretical Foundation

## 1. Heat potential applied

- Soil → assumed to be isotropic
- Temperature field of frozen soil → approximated to be steady state.
- Freezing pipe → regarded as a point source (cold source or heat sink)

## 2. Based on potential superposition

- Multiple freezing pipes → multiple point sources exist in the plane
- Heat potential at an arbitrary point in the plane equals the superposition of the heat potentials

# Highlights of the Paper

We adopted potential superposition theory in research, and concluded 4 steady-state temperature fields.



- Temperature field of a single freezing pipe
- Temperature field of two freezing pipes

- Temperature field of three freezing pipes
- Temperature field of four freezing pipes

# Temperature Field of Three Freezing Pipes

Steady-state temperature fields produced by three freezing:

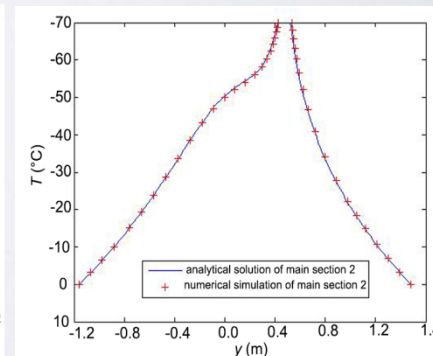
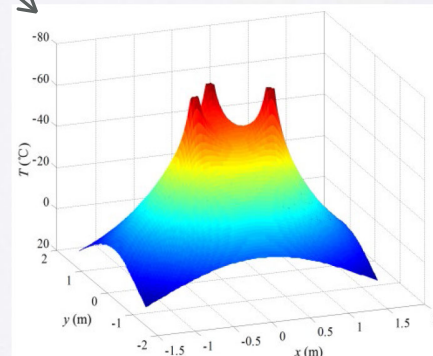
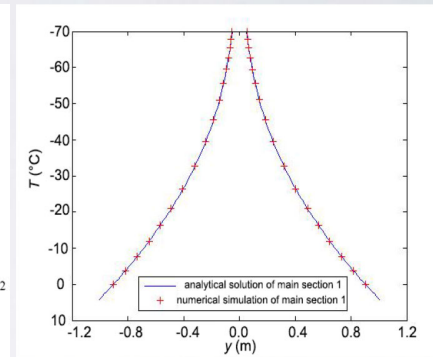
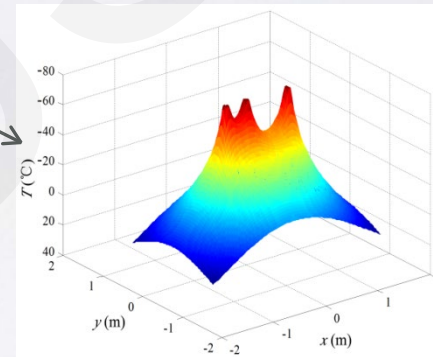
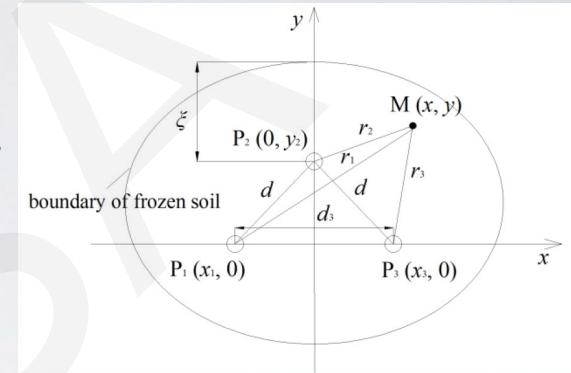
➤ Temperature field of three freezing pipes in an arbitrary arrangement

➤ Temperature field of three freezing pipes in a linear arrangement with equal spacing

➤ Temperature field of three freezing pipes in a linear arrangement with unequal spacing

➤ Temperature field of three freezing pipes in a right triangle arrangement

➤ Temperature field of three freezing pipes in an isosceles triangle arrangement



# Temperature Field of Four Freezing Pipes

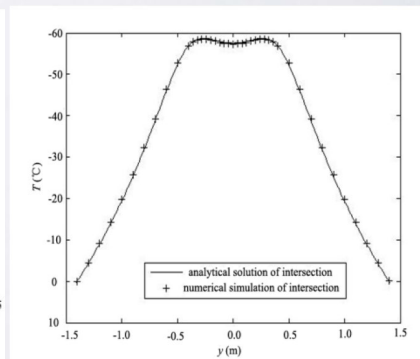
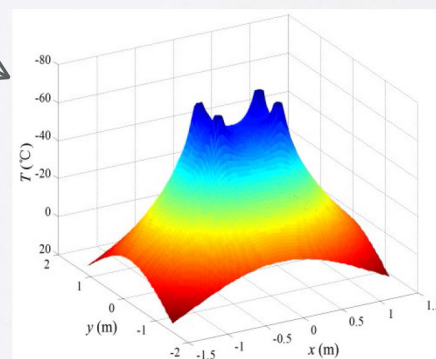
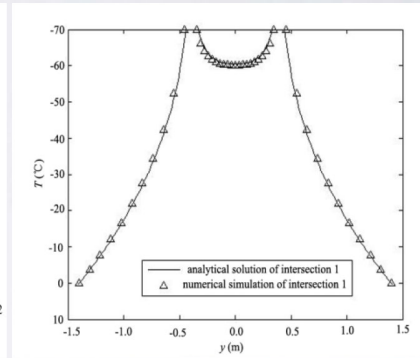
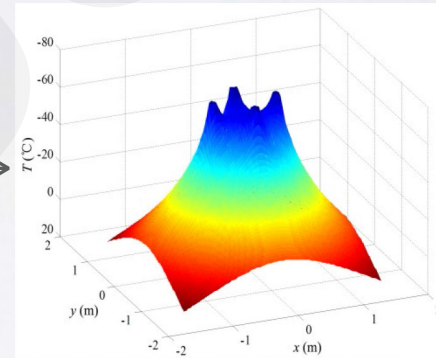
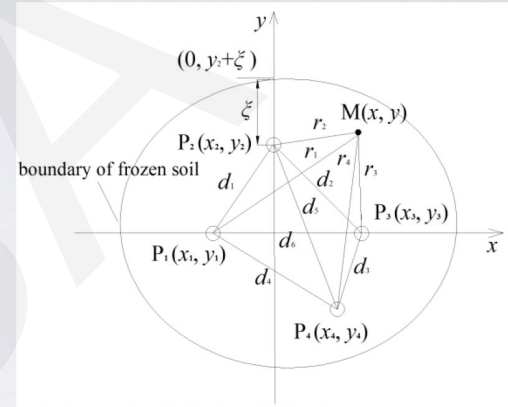
Steady-state temperature fields produced by four freezing:

➤ Temperature field of four freezing pipes in an arbitrary arrangement

➤ Temperature field of four freezing pipes in a linear arrangement with equal spacing

➤ Temperature field of four freezing pipes in a rhombus arrangement

➤ Temperature field of four freezing pipes in a rectangle arrangement



# Conclusion

By adopting potential superposition theory, we found a deriving method to the steady-state temperature field frozen by multiple freezing pipes. The conclusion derived from this method fits precisely with the result obtained in numerical simulation.

