Numerical Studies of Bridge Foundation Temperature Control Technology in Permafrost Regions

Xiuyun Zhao¹ and Jian Wang²
Shandong Xihe University, Shandong, Jinan 250000, China
Qilu Transportation Construction Group Co., Ltd, Shandong, Jinan 250000, China
Email: 290706554@qq.com

Abstract. Under the influence of global warming, the engineering structure stability of the permafrost regions are under the threat of a very strong, therefore, it is necessary for climate change under the influence of the pile foundation to study the temperature field of frozen soil area. In this paper, the bridge pile foundation under the condition of the temperature rise over the next 50 years, thermal probes of different forms (pile arrangement within one, two, three; pile arrangement outside two, three) are analyzed and compared. Calculation results show that thermal probes pile foundation have active cooling effect, can guarantee the stability of the bridge pile foundation; In a pile outside the same number of root pile layout arrangement effect is good.

1. Introduction
In recent years, significant degradation of permafrost in permafrost area with the influence from the global warming. Degeneration embodied in ground temperature, maximum frozen soil depth decreases and the marked increase in permafrost area is shrinking, seasonal frozen soil area increases, the lower bound of permafrost rise generally, presents the general trend of degradation of permafrost [1-3]. In order to ensure the overall stability of the bridge foundation engineering, trying to adopt thermal probes processing measures. Thermal probes by taking advantage of natural energy foundation, under the effect of temperature difference to drive the internal cooling of vapor liquid two relative flow loop, through evaporation evaporation heat effect to reduce the temperature of permafrost around, increase the cold permafrost itself reserves, raise the thermal stability, protecting permafrost. Thermal probes technology is new technology has a broad application prospect, especially in the global temperature rise environment, its effect is more apparent. Practice has proved that thermal probes can be very good to prevent the permafrost and thawing settlement, frost heave in the qinghai-tibet railway, highway subgrade embankment in permafrost regions has important stage results, later will be gradually popularized in the construction in permafrost regions.

2. Thermal pile thermosiphon
The hot rod is a kind of coreless gravity heat pipe, which transfers heat through liquid vapor two-phase conversion convection circulation. The hot rod is composed of a closed vacuum chamber filled with low boiling point working medium. The upper part of the tube is equipped with a heat sink. The lower part of the tube is buried in permafrost. The upper part of the tube is a heat sink, the middle part is an insulation section, and the lower part is an evaporation section. When the lower ambient temperature is higher than the upper ambient temperature, the working medium in the pipe of the hot rod evaporation section will evaporate into steam and rise. Because the upper ambient temperature is
lower than the lower ambient temperature, when the steam rises into the upper condensation section, it will be cooled by the cold air outside the pipe and condensed into liquid. Under the action of gravity, it will return to the lower space. Through the evaporation of the working medium cycle, the condensation process will make the lower ring The heat of the environment is continuously sent to the upper environment, that is to say, the cooling capacity of the upper environment is continuously sent to the lower environment, so that the temperature of the lower environment is continuously reduced; until the upper and lower temperatures are equal, the cooling process of the lower environment stops[4-7].

3. Numerical Analysis Model and Boundary Conditions

3.1. Numerical Analysis Model
Thermal pile effective influence range is a three-dimensional heat transfer problem. The mathematical model is strongly nonlinear problem, which can’t use a general method to solve it. Therefore, in this paper, the three-dimensional numerical analysis was used by finite element software ANSYS. Six different forms (pile arrangement within one, two, three ; pile arrangement outside two, three) were studied for temperature effect. The coefficient of thermal conductivity of thermal probes is 10.0.

The bridge pile foundation is modelled by Solid70. The thickness of snow layer is 10cm and it is assumed to be above the ground surface. The heat capacity of the snow is 2100, coefficient of thermal conductivity is 0.09. Birth and death element method is adopted in calculation process control snow every year only applied in the winter (from November to March), the snow layer is killed in other months.

The variation of soil parameters with temperature is discontinuous. The new variable enthalpy H is used, which is the function to be solved. Enthalpy is the integral of the product of density and specific heat to the temperature, which is given by the following formula (1).

\[ H = \int \rho c(T)dT \]  

(1)

\[ Q = L \rho_d (w - w_u) \]  

(2)

where \( Q \) ——phase change thermal, \( L \) ——crystallization or melting latent heat of water, \( w \) ——total moisture content, \( \rho_d \) ——dry density of soil, \( w_u \) ——unfrozen water holdup in the permafrost.

In the model, material thermal physical parameters are shown in table 1, the finite element numerical simulation model is shown in figure 1.

| soil                  | thick/ m | \( \rho_d \)/kg/m³ | \( \omega \)/% | \( C_s \)/kJ/(m³ °C) | \( C_f \)/kJ/(m³ °C) | \( \lambda_s \)/W/(m³ °C) | \( \lambda_f \)/W/(m³ °C) |
|-----------------------|----------|--------------------|---------------|----------------------|----------------------|-----------------------------|-----------------------------|
| sod and peat loam     | 0.6      | 800                | 90            | 3814                 | 2425.6               | 0.8                         | 1.55                        |
| gravel and clay       | 5.4      | 1500               | 35            | 3450.2               | 2542.7               | 1.36                        | 2.12                        |
| Cement concrete       | 19       | 1800               | 3             | 1731.3               | 1580.8               | 0.60                        | 0.60                        |
| cement concrete       | 10       | 2500               | 3             | 2300                 | 2300                 | 1.73                        | 1.73                        |

Table 1. The pile and the soil thermal physical parameters.
3.2. Boundary Conditions
According to the boundary layer principle [6], the upper surface is represented by the first type of boundary condition which changes with time, namely:

\[ T_s = T_a + \Delta T \]  

(3)

\[ T_a = T_0 + g(t) + 13 \times \sin\left(\frac{2\pi t}{31536000}\right) \]  

(4)

Where: is the temperature applied to the upper surface in the calculation; when the average temperature is -6 °C (low temperature frozen soil), = 3.5 °C; when the average temperature is -4 °C (high temperature frozen soil), = 3.2 °C[6]; is the atmospheric temperature; is the annual average temperature; represents the global warming effect, = 0.05 °C/a.

4. Results and Analysis
After finite element calculation, the results are extracted for processing. The temperature calculation results of pile-soil interface under different heat pipe arrangement schemes are obtained. Organize it, as shown in Fig. 2 and Fig. 3.
Figure 3. Temperature curve with depth in setting thermal pile when the average temperature of -4°C.

It can be seen from Fig. 2 and Fig. 3 that when the soil condition is medium moisture content, no matter it is high-temperature frozen soil or low-temperature frozen soil, the five arrangement schemes in the calculation can prevent the degradation of frozen soil. When the high temperature frozen soil and soil condition are high moisture content, the arrangement scheme of one pile can not prevent the degradation of frozen soil, and other hot rod arrangement schemes can. When the low-temperature frozen soil and soil conditions are high moisture content, one pile can not play a role in cooling, other hot rod layout schemes can only play a role in cooling the area near the evaporation section, and the frozen soil area far away from the evaporation section of the hot rod can not prevent degradation.

5. Conclusion

Through theoretical analysis and finite element calculation, we can get the following conclusions:

In order to prevent permafrost degradation in low temperature permafrost area, it is suggested to use two hot rods in the area with low moisture content in soil condition, and other refrigeration measures in the area with high moisture content in soil condition to prevent permafrost degradation;

In the high temperature frozen soil area, in order to prevent the degradation of frozen soil, in the area with low water content in soil condition, one hot rod arrangement scheme can be used in the pile considering economic problems; in the area with high water content in soil condition, two hot rods refrigeration scheme is recommended.

No matter in high temperature or low temperature frozen soil area, it is recommended to consider two hot rods outside the pile for cooling under the same construction difficulty and economic consumption conditions, because the cooling effect outside the pile is better than that inside the pile under the same number of piles.

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