OPTIMIZATION OF ENGINEERING SOLUTIONS FOR THERMAL STABILIZATION OF SALINE PERMAFROST SOILS AT BASES OF STRUCTURES BY MEANS OF TWO-PHASE HEAT PIPES

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Abstract

Construction on saline permafrost soils is an actual engineering problem. Its solution would be impossible without soils thermal control and thermal stabilization for preventing dangerous cryogenic processes and their negative consequences concerned with violations of permafrost temperature conditions. The adequate technique for soils thermal stabilization is two-phase heat pipes also called thermal stabilizers (TS). The paper presents thermotechnical calculations results and efficiency evaluation for different TS types. We suggest basic criteria for the choice of optimal TS type, disposition and TS-to-TS spacing. Thermal stabilizer TMD-5 designed by "Inter Heat Pipe" Corp. is shown to be preferable TS type under complicated geocryological conditions of Yamal peninsula. TMD-5 application increases bearing capacity of metallic piles in saline permafrost soils up to 2.9 times or by 190%.

KEYWORDS

Thermal stabilization, two-phase heat pipes, saline soils, permafrost, construction, reliability.

INTRODUCTION

Engineering structures reliability control is the actual problem of civil and industrial engineering in the Northern and Eastern regions of Russia where permafrost soils are prevailing. Geocryological conditions and their variability essentially effect bases of structures stability, and thereby they determine stability and reliability of buildings and engineering structures in cold regions.

A great number of buildings, roads, dams, pipelines, power transmission towers, etc. have experienced movement or have failed, e.g. in the northern part of Western Siberia there are more than 4000 tilted power transmission towers [1]. The dominant origin is change (violation) of soils thermal conditions under the influence of natural and man-caused factors. This has led to bearing capacity loss, perennial thawing or freezing and frost heave. Permafrost soils temperature control is needed to prevent dangerous cryogenic processes and their negative consequences concerned with violations of permafrost temperature conditions. The development of temperature control technique is an important scientific and practical problem.

OVERALL PERFORMANCE

A basic engineering solution for permafrost thermal control is soils thermal stabilization by means of their cooling and freezing with cooling devices. Two-phase heat pipes called "thermal stabilizers" (TS) are mainly used in construction as cooling devices. They are also called vapor-liquid thermo-siphons, thermo-piles, seasonal cooling devices (SOU in Russian) and so on.

A two-phase TS transfers heat from its underground part (evaporator) to the aboveground part (condenser) owing to a cyclic process: liquid heat carrier evaporates absorbing heat from soil, the vapor lifts and condenses with heat release and dissipation to the ambient air, then liquid heat carrier trickles down. Two-phase thermal stabilizers have extremely high thermal conductivity and cooling efficiency, much more than liquid cooling devices, and their application area is essentially wider. Their additional advantages are low temperature gradients, small diameter and mass, easy transportation and installation etc. Thus, in this paper we consider only two-phase thermal stabilizers (TS).

The development of gas fields of Yamal peninsula where saline permafrost soils are widely spread would be impossible without thermal control and stabilization by means of different types TS. Great salinization of soils decreases their phase change temperature from zero to –2 … –3 centigrade and below. In this connection the choice of the most effective TS types and optimization of engineering solutions for disposition and TS-to-TS spacing become the actual problems when bases of structures are designed. We solve these problems using mathematical simulation of soils temperature fields with the help of the computer program "HEAT" developed at the chair of geocryology in Moscow State University.

CALCULATIONS AND RESULTS

The comparative thermotechnical calculations have been performed for three TS types: TK32/12 designed by "Fundamentstroyarkos" Corp.; TMD-4 and TMD-5 designed by "Inter Heat Pipe" Corp. TK32/12 and TMD-4 are made from carbon steel, and TMD-5 – from aluminum alloy. TK32/12 have smooth-wall tube whereas TMD-4 and TMD-5 contain capillary elements in their evaporators [2]. While calculating we assumed that the dosed amount of ammonia was used as a heat carrier in all TS types. Note that thermal stabilizers with smooth-wall steel tubes are known to be essentially less effective than stabilizers made from aluminum alloys.

To evaluate the efficiency of TS as cooling devises we attended their basic characters, they are:

- internal thermal resistance,
- external thermal resistance in the evaporation zone,
- thermal resistance of the condensation zone,
- turn-on time,
- temperature gradient along evaporator.

To compare the efficiency of different types TS we have realized mathematical simulation of soils temperature fields under the building with the width of 48 m, the floor thermal resistance (including the air in the cellar) R = 5 $m^2 \cdot K/W$ and the temperature inside the building +18 °C. The results are presented in the table 1.

Table 1. Single TS cooling effect under the building after operation during 5 years

TS type	Radius of thermal influence zone, m	Thawing depth under the building, m	
		inside the thermal influence zone	outside the thermal influence zone
TK32/12	2.30	1.25	2.2
TMD-4	3.30	0.0	2.2
TMD-5	4.60	0.0	2.2

Calculations show that thermal stabilizer TK32/12 do not prevent perennial thawing due to building thermal effect, and this is not acceptably for saline permafrost soils with ice strata. TMD-4 is more active but the most effective is TMD-5 made from aluminum alloy. In comparison with steel thermal stabilizers TMD-5 shows the number of advantages, namely:

- lesser internal and external thermal resistance in the evaporation and condensation zone,
- extremely low temperature gradient along evaporator (≤ 0.1 K/m),
- higher freezing rate and cooling efficiency (efficiency coefficient is about 0.75),
- lesser turn-on time (0.8–2 hours compared with 8–12 hours for steel TS),
- lesser TS amount needed due to more spread of thermal influence,

– easy transportation and installation because of small mass (1.2 kg/m).

Thermotechnical calculations and simulation results lead to the conclusion that thermal stabilizer TMD-5 designed by "Inter Heat Pipe" Corp. (Fig. 1) is preferable under complicated geocryological conditions of Yamal peninsula.

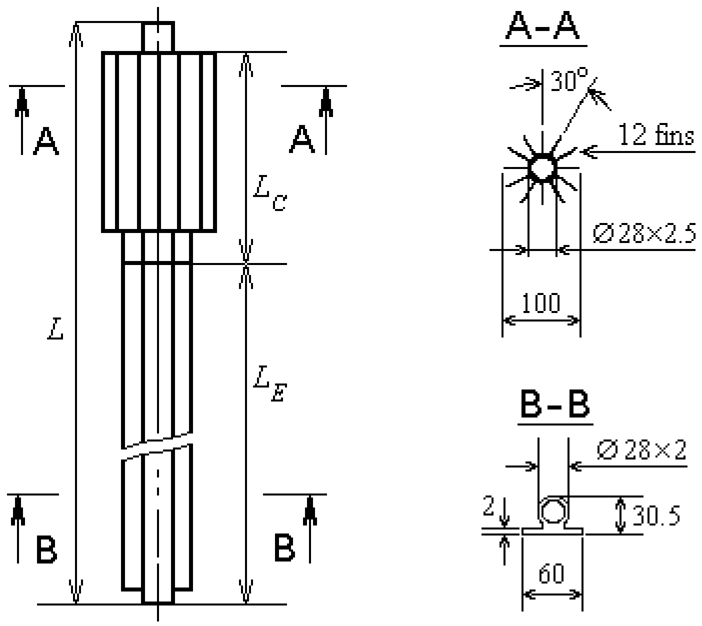

Fig. 1. Scheme of thermal stabilizer TMD-5: L – total length (4 to 11.5 m), L_C – condenser length (1 to 2 m), L_E – evaporator length (3 to 9.5 m)

Optimization of engineering solutions for soils thermal stabilization (TS disposition and amount) should be performed depending on building thermal conditions, design features, climatic and geocryological conditions and selected TS type. The optimization should be based on thermotechnical calculation and simulation.

As an example the fig. 2 presents the simulation results for cooling contour formed by TMD-5. Temperature field horizontal cross-section is shown after the first active season.

The simulation shows that the cooling contour from TMD-5 decreases soil temperature around piles by 5 degrees at the first year of operation, and contour thermal influence spreads up to 6 m. At the next years cooling effect will be grow, and piles bearing capacity will increase.

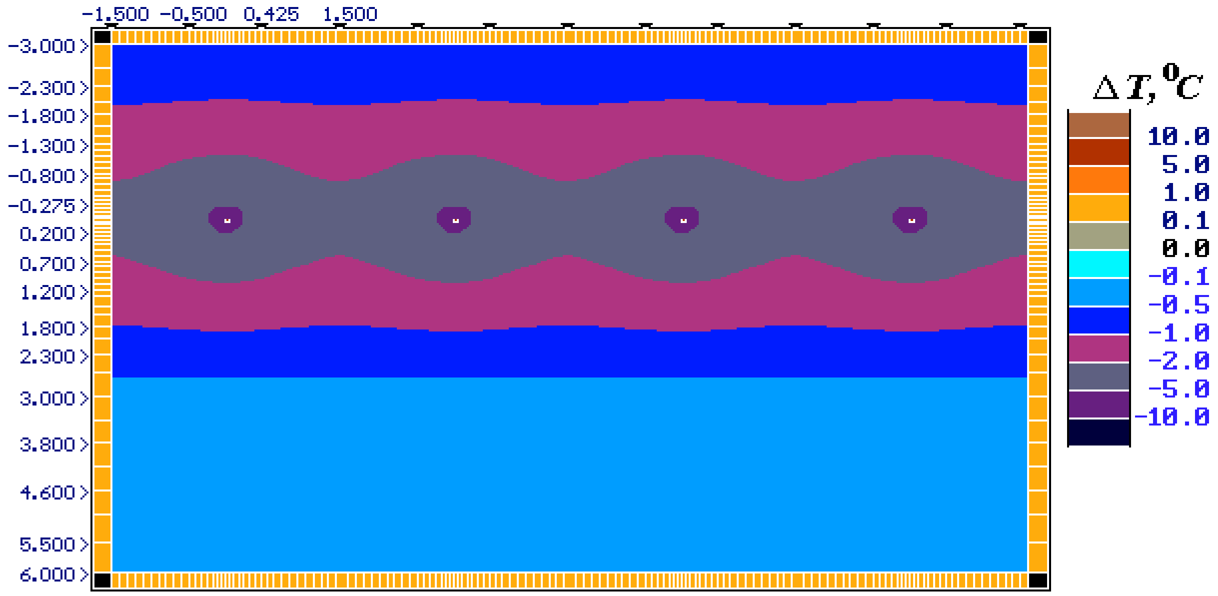

Fig. 2. Contour from TMD-5 cooling effect after the first active season

High efficiency of TMD-5 application becomes apparent in sharp increasing of piles bearing capacity, and this is very important for saline permafrost soils. Calculations in accordance with construction regulations (SNiP in Russian) [3] show that using of TMD-5 increases bearing capacity of metallic piles up to 2.9 times or by 190 %.

CONCLSIONS

Construction on saline permafrost soils is impossible without soils thermal control and stabilization for preventing dangerous cryogenic processes and their negative consequences concerned with violations of permafrost temperature conditions. The adequate technique for soils thermal stabilization is two-phase TS. Thermotechnical calculations and simulation results are shown thermal stabilizer TMD-5 designed by "Inter Heat Pipe" Corp. to be preferable under complicated geocryological conditions of Yamal peninsula. TMD-5 application increases bearing capacity of metallic piles in saline permafrost soils up to 2.9 times or by 190 %.

References

1. Lyazgin A.L., Bayasan R.M., Chisnik S.A., Cheverev V.G., Pustovoit G.P. Stabilization of pile foundations subjected to frost heave and in thawing permafrost // *Proc. of 8th Intern. Conf. on Permafrost*, *Zurich, Switzerland.* 2003. Vol. 2. Pp. 707–711.
2. Bayasan R.M., Korotchenko A.G., Lobanov A.D., Pustovoit G.P. THP-based energy-efficient technologies experience in cold regions // *Proc. of 13th Int. Heat Pipe Conference (13th IHPC), Shanghai, China.* 2004. Vol. 2. Pp. 414–419.
3. SNiP 2.02.04-88. Construction Regulations and Rules. Bases and Foundations on Permafrost Soils. Gosstroy, Moscow, 1990.