The laboratory investigation of load-bearing capacity of the metal pile depending on the local geocryological conditions

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ABSTRACT

Weak thawing soils around the metal piles are the main danger during construction of engineering structures located in the cryolithozone. The ice inside the soil gives thermokarst dips and settlement while thawing. High-precision calculations of the load-bearing capacity of soils and accurate forecasts of the amount of thawing in summer are necessary for improving the reliability of engineering structures. This paper shows a short report about laboratory static load tests of metal piles (pipe 60 mm in diameter and 600 mm in length with thickness of side 1.5 mm) in near to permafrost condition. First test was for normal conditions with outside temperature +23℃ and thawed soil, but for second and other tests metal pile stood on the frozen soil after freezing in freezing room where outside temperature was -10℃. There were three temperatures of the frozen soil for tests: -5℃, 0℃, +5℃ with partial thawing of the top layer of soil.

Keywords: Metal pile, Permafrost, Soil, Load-Bearing capacity, Static

1 INTRODUCTION

The problem of the reliability of construction in freezing soil ground has been studied by many scientists. The most experienced researchers in this area are from Korea.

Permafrost occupies 65% of the territory of Russia. Development of effective construction methods in specific conditions of these areas is very important. It is necessary to provide protective measures for preventing buckling of foundations during period of freezing of ground.

With thawing of the soils load-bearing capacity is decreasing. Because of that we offer to use thermopiles (season-cooling devices), which are used as foundation of engineering structures.

2 DESCRIPTION OF MODELING STAND

The aim of laboratory investigation was to prove the possibility of using metal piles in frozen and thawed soils. Because of that we have made soil similar to local in Sakhalin Region, Russia.

There were four tests with different soil conditions. First was made with outside temperature +23℃ and with thawed soil without freezing, second and other was made after freezing with partial thawing. Outside temperature in freezing room was -10℃, temperatures of the frozen soil were -5℃, 0℃, +5℃.

3 LABORATORY EXPERIMENTS

The experiments were conducted in the test chamber.

The metallic chamber has one layer. Model of an experimental soil include mixture consisting of 30% fine sand and 70% marine clay, as it was typical of the Sakhalin Region, Russia with density 1.75 g/cm^3 and Specific gravity 2.82 g/cm^3.

In the geotechnical laboratory of the National University of Incheon (INU, South Korea), the physical and mechanical properties of soil were determined.

3.1 Model Test Box

Laboratory model tests were conducted in a box. The chamber size was 580 mm (length) × 380 mm (width) ×700 mm (height). Four sides of the box were made of steel planks, and covered with term materials.

The model test box was braced with angle irons to avoid yielding during soil placement and loading of the model foundation. The inside of the test box was made as smooth as possible to reduce friction with the edges of the model foundation during the application of load.

3.2 Model of metal piles

Laboratory load-bearing capacity tests were conducted using a model of the metal pile foundation with next dimensions: 60 mm in diameter and 600 mm in length with thickness of side 1.5 mm. To ensure rigidity, an aluminum plate having the same width as the model foundation was mounted on its top. Figure 1 shows average temperatures each of months in Pogibi (Sakhalin Region).

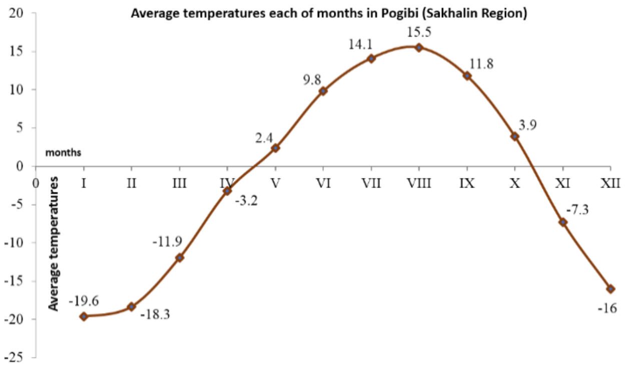

Fig. 1. Graph of average temperatures each of months in Pogibi (Sakhalin Region).

3.3 Conducting the experiments

Four series of experiments were carried out in the conditions of the geotechnical laboratory: the first series was for analysis of the stability of the pile and the interaction of the soil base with the pile on thawed soil with outside temperature +23 °C; the second, the third and the fourth series were for determining the stability of the pile and the interaction of the soil base with the pile in the freezing soil -5°C, 0°C and with partial thawing to +5°C.

Increasing step-by-step loading on the pile foundations was held. Load step was equal to 0.01 N. The model of the pile foundation was loaded to achieve the maximum load-bearing capacity.

4 CALCULATION OF THE LOAD BEARING CAPACITY OF THE BASE

Calculation of the load bearing capacity of the base has been made with help of SR 25.13330.2012 "Soil bases and foundations on permafrost soils".

4.1 Methods of calculation

The main condition of calculation of base by first group of limit states is following:

$$F \leq Fu/\gamma_n, \quad (1)$$

where F - calculated load on the base; Fu – load bearing capacity of the base, determined by calculation, γ_n - coefficient of reliability on responsibility of construction.

Calculation of the load bearing capacity of base was carried out using the formula

$$\boldsymbol{Fu = \gamma_t \cdot \gamma_c \cdot \left(RA + \sum_{i=1}^{n} R_{af,i} \cdot A_{af,i}\right)} \quad (2)$$

where γ_t - temperature coefficient, taking changes in the temperature of the ground base due to random changes in the temperature of the outside air; γ_c - coefficient of conditions of ground work; R - calculated resistance of frozen soil under the lower end of the pile, kPa; A - the area of pile support on the ground, m^2; $R_{af,i}$ - calculated resistance of frozen soil or ground solution to shear along the lateral surface of pile frost, kPa; $A_{af,i}$ - surface area of the freezing surface of the i-th layer of soil with the side surface of the pile.

4.2 Numerical simulation

General equation describing the freezing and thawing processes for a transient thermal regime in a three dimensional soil space can be expressed as following:

$$C_{th(f)}\rho\frac{\partial T}{\partial t} = \lambda_{th(f)}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + q_V \quad (3)$$

where $C_{th(f)}$ - specific heat of soils (frozen or thawed), J/kgK; ρ - soil consistency, kg/m³; T – temperature, K; t – time, c; $\lambda_{th(f)}$ - thermal conductivity of soil (frozen and thawed), W/mK; x, y, z – coordinates, m; q_V- internal heat source capacity, W/m³.

The core of a mathematical modeling of thermophysical processes in "Termoground" program is the model of high ice, thawed and frozen soils offered by N.A. Tsytovich, Y.A. Kronik and V.F. Kiselev.

The major factors determining the defined surface temperatures on the embankment elements and the adjacent territory are the atmospheric air temperature and the heat exchange conditions between the air and the structure surface that depend on the wind conditions, solar radiation, vaporation, and others.

The calculation value of the defined average monthly air temperature is determined from the formula:

$$T_c = T_\alpha + \Delta t_r - \Delta t_e \quad (4)$$

where T_α is average monthly air temperature,°C; Δt_r and Δt_e are corrections to average monthly air temperatures due to solar radiation and evaporation, °C.

The correction to air temperature due to solar radiation (Δt) is calculated according to formula:

$$\mathrm{t_r} = \frac{R}{0.073\alpha} \quad (5)$$

where R is monthly sum of radiation balance for the considered element of the surface, kkal/sm^2·months; α is surface heat exchange coefficient, kkal/m^2·h·°C, and its empirical-formula dependence is:

$$\alpha = 10\sqrt{V} \quad (6)$$

where V is wind velocity.

The monthly sums of radiation balance for horizontal surfaces are determined from the formula:

$$R_o = Q_o \times k - 0.42 \tag{7}$$

where Qo is average monthly sum of total solar radiation striking the horizontal surface, kkal/sm2·months; k – empirical coefficient in terms of the surface reflecting capacity (albedo).

The monthly sums of radiation balance for bevel faces (subgrade embankments) are determined from the formula:

$$R_\beta = (m_\beta I_o + P_\beta D_o) \times k - 0.42 \tag{8}$$

where I_o and D_o – average monthly sums of direct and diffuse radiations striking the horizontal surface, kkal/sm^2·months, the values being taken from the climatological guide;

m_β – nondimensional coefficient in terms of the bevel face angle to horizon and spatiolization of the face for beam radiation intake.

P_β – coefficient in terms of the bevel face angle to the horizon and spatialization of the face for a sky radiation intake that is determined from the formula:

$$P_\beta = \cos^2 \frac{\beta}{2} \tag{9}$$

where β– angle of the bevel face to the horizon, degrees.

The thermophysiscal characteristics of the roadway and roadbed soils in thawed and frozen states are taken in accordance with the SR 25.13330.2012 – Permafrost Foundation Engineering Standards.

The relative thawing strains of permafrost are determined according to the results of the standard laboratory tests. In this case the relative stresses are calculated according to the formula:

$$\varepsilon_{th} = A_{th} + \delta_{ith} \tag{10}$$

where A_{th} is the relative strain of thaw thermal subsidence; δ_{ith} is the relative strain of thaw loading subsidence.

$$\delta_{ith} = m_{0th} \cdot p_i \tag{11}$$

where m_{0th} is the coefficient of compressibility of thaw soil (MPa-1); p_i is the compacting vertical stress (MPa).

5 EXPERIMENTAL RESULTS

The maximum load-bearing capacity was obtained for -5 °C temperature of the soil. Figure 2 shows the experimental stand.

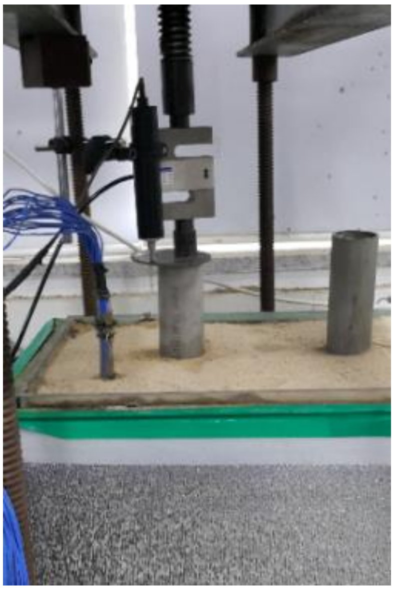

Fig. 2. Test model.

The results of the ultimate bearing capacity of pile foundations with a change of temperatures T=+23°C, +5°C, 0 °C, -5 °C are presented in Table 1.

Table 1 Results of the experimental test of piles.

Test	L/D (cm)	Temperature, °C	Ultimate bearing capacity q_u, kPa
1	10	+5	2086.54
2		0	2882.72
3		-5	10130.68

Model tests of piles in ordinary and frozen ground conditions showed different results.

Figure 3 shows results of static load tests and settlement.

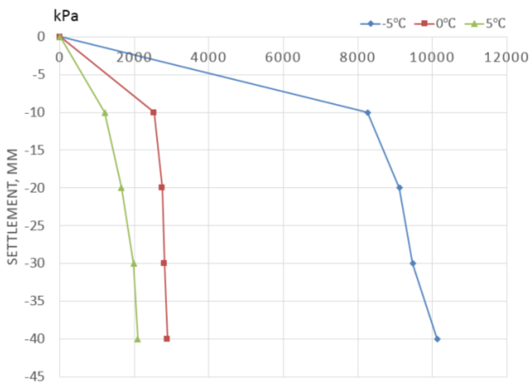

Fig. 3 Graph load-settlement of piles.

6 THEORETICAL RESULTS

The load-bearing capacity at different locations and temperatures were obtained (Figure 4). Graph shows load-bearing capacity - temperature dependence of ground in the annual period on average depth of basement in the permafrost conditions along the route «Kuyumba-Taishet-Kozmino» in Russia. It is observed that ground temperature variation influences value of the load-bearing capacity. It is also observed that the lower temperatures are, the larger value of the load-bearing capacity is.

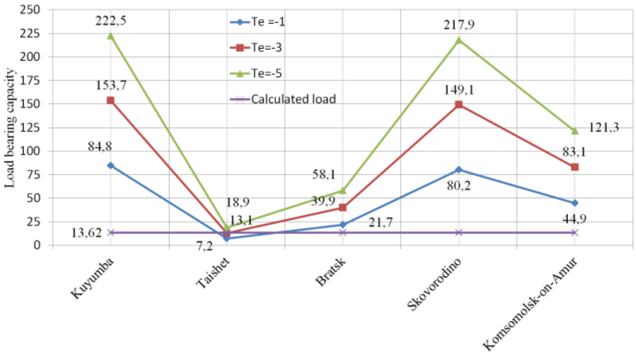

Fig. 4. Evolution of the load-bearing capacity at different locations and temperatures with compare of load on the thermopile.

Comparing theoretical results with laboratory shows in Table 2. Theoretical results are close to laboratory.

Table 2 Comparing theoretical results with laboratory

Test	Temperature, ℃	Laboratory ultimate bearing capacity q_u, kPa	Theoretical ultimate bearing capacity q_u, kPa
2	+5	2086.54	2400
3	0	2882.72	3250
4	-5	10130.68	11650

Note that the thermodynamic calculation does not consider heating effect of infiltration of precipitation into the soil and transverse filtration of groundwater, because of absence of monitoring data. Therefore, forecasted temperature fields different from original data to the side of lower temperatures. This fact must be considered for cooling and anti-deformation measures.

7 CONCLUSION

The performed analysis of the proposed solution showed increasing of load-bearing capacity with lowering of soil temperature up to 5 times. Because of that we offer to use thermopiles to keep soils in frozen state and ensure the stability of structures on piles.

Theoretical results are close to laboratory. Theoretical results 15% more than laboratory, because calculation does not consider heating effect of infiltration of precipitation into the soil and transverse filtration of groundwater, because of absence of monitoring data.

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