Increase in Efficiency of Cooling of the Frozen Basis at the Expense of the Thermal Insulation Blind Area and Vertical Self-Cooling Devices (SCD)

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Abstract. At traditional decisions the bases of residential buildings of the soil constructed with preservation of a frozen state, basis temperatures in an average zone under the building are much lower, than in extreme zones. It reduces bearing capacity of piles on side axes. In this article, the constructive solutions allowing to cool more evenly the basis due to application additional of the cooling and preserving devices are considered. Regularities of formation of temperature condition of frozen soil were carried out by numerical methods by means of the TEMPA program. on the example of the residential building in permafrost zone. The constructive decision includes the pile bases and the high ventilated underground. The executed calculations showed an opportunity to lower temperature in the work area of extreme piles up to the temperature in a zone of average piles at the expense of the warmed blind area and vertical self-cooling devices (SCD).

1. Introduction

Absolute majority of stone residential buildings in the cities located in a zone of steady permafrost soil are built by the I principle with saving of a frozen status of soil of the basis. Here belongs such cities as Norilsk, Yakutsk, Vorkuta, Peace, etc. As the bases of these buildings the piles in frozen soil are most widely applied. Special constructive solutions are applied to saving of soil of the basis in a frozen status. [1,2,3]

At construction of buildings by the I principle there are two approaches to saving of soil in a frozen status.

The first approach is directed to cooling of soil of the bases are cold air for what the building rises over a planning surface. The main solution is superficial cooling here [4,5]. Similar constructive solutions were proposed in the form of the ventilated pipes of big section, the ventilated channels, adding etc. [6,7]. However, as practice showed, these devices at small cross-sectional area grow with hoarfrost, ice and their efficiency decreases. It is possible to carry out additional cooling of soil of the basis by use of the vertical self-cooling devices (SCD) lowering temperature in the basis at a depth of the work area of a pile and also the heat insulation stacked on surfaces of SCD [8]. Primary benefit of these methods − saving of the traditional solutions which proved the reliability and durability at minimum flows on operation.

The second approach allows to refuse the ventilated underground due to application of the horizontal SCD located in high layers of soil. Structurally it can be executed at the expense of the
thin metal pipes which are partially filled with the easily boiling liquid like Freon 12 [9-11]. Of course productivity of cold pipes is much less as the surface of cooling 10 times less than an underground surface, and temperature is higher due to losses at cold transportation. But it can be compensated for the account of warm adding and a layer of effective heat insulation between frozen soil and the warm building.

Such approach allows to solve the main problem of cold undergrounds – laying of utilities in a cold zone. But there is other operational problem – durability of horizontal SCD. Pipes keep within under the building without access for repair. Their service life is much less than building. These pipes are subject to temperature deformations as they during the warm period of year heat up to soil temperature, and are cooled up to the coolant temperatures in the winter that it is below $10 - 15 \, ^{\circ}C$. Besides temperature deformations of the soil both under heat insulation, and over heat insulation are possible. For the engineering constructions aving sufficient flexibility it can be admissible. Therefore these devices are effectively used to the bases of buildings and constructions with limited time of operation and also to freezing of soil in faults [12]. This first of all oil and gas and network construction of the power transmission line and also automobile and railway constructions. Such method can be implemented in sports constructions, especially in ice arenas as it is made in Yakutsk.

But for stone residential buildings, with high constructive rigidity, such solution can lead to deformation of constructions of the building. As the main requirement to the bases of capital residential buildings – high reliability and durability at minimum flows on operation preference is given to traditional solutions. Under buildings leave free airspace, the so-called ventilated air spaces (VS). For this purpose the building is lifted on one and a half – two meters over a planning surface. Standard constructive solutions of a base part of the building with VP it is presented in figure 1.

![Figure 1](image_url)

**Figure 1.** To Building section fragment constructed with saving of the basis in a frozen status: 1 – inhabited floor; 2 – technical floor; 3 - VS; 4 – communications.

The feature of cooling of soil of the basis at the expense of VS is irregularity of cooling of the basis. In the middle of the building a surface of an underground are closed from sunshine, and it is cleaned from snow. On side borders of the building temperature of soil is much higher due to influence of soil with natural temperature condition. Here the surface is covered with snow, in the summer heating is carried out due to insolation, and as from South side, and northern. Length of light day in July reaches till 22 o'clock in day. As a result extreme piles are in more adverse conditions, than averages. At such design solutions of temperature of the basis in an average zone under the building is much lower, than in extreme zones. It reduces bearing capacity of the piles located at the edges of the building.
In this article the constructive solutions allowing to cool more evenly the basis at the expense of a combination of the ventilated underground, heat-insulating a blind area and vertical SCD are considered. As such devices the steel concrete pile with the built-in cooling device in the form of a metal pipe with a diameter of 120 mm is accepted. A pile 8 m long and with a section of 30x40 cm are developed at institute “YakutNIPROalmaz” of Mirnyi [13]. Schematically to construction of a cold pile of CX-1-6/8 it is shown in figure 2.

Figure 2. The self-cooled pile with the built-in thermosiphons: a) - schematic device of a “cold” pile; b) - a coaxial thermosiphon with the step diaphragm implementing the radial scheme of a crossover of the heat carrier; c) - construction of a diaphragm with the gaps eliminating possibility of summer circulation of the heat carrier.

As the liquid heat carrier kerosene is applied usually. In a thermosiphon the coaxial structure allowing to increase efficiency of cooling due to division of the fluid flows moving diversely is applied. Placement of a thermosiphon in a pile improves heat exchange conditions on a thermosiphon surface, promotes fast cooling of the soil adjacent to a pile that sharply increases bearing capacity of the base and also reliability and durability of the device [14,15].

For more exact impact assessment of the cooling effect of SCD and heat-insulating blind areas on temperature condition of the frozen foundation of the residential building are executed computational modeling.

There are many program complexes for calculation of the frozen bases. Generally they are adapted for a solution of specific engineering objectives and are suitable for researches by means of numerical models a little. With permafrost soil are developed for calculations of thermal interaction of buildings and constructions several such computer programs. ‘HEAT’ program of department of geocryology of Lomonosov Moscow State University; ‘FROST’ program of the Siberian department of RAS; KRIOS program of Fundamentproyekt institute [16-20].

In this work computational modeling of temperature condition of the cooled soil basis were carried out by means of developed in MGSU - MISI of the program ‘TEMPA’ complex (the certificate on the state registration 2016618937). The complex is developed for a solution of non-stationary heatphysical tasks with phase transitions of the connected moisture in soil in a range of negative temperatures. As physical model the enthalpy method is accepted [21].
2. Basic data and calculations
The three-dimensional soil array in respect of 5x30 m and 20 m in depth, is divided on depth into blocks from 0.75 to 2.0 m in size. Under the building 14 m wide with there is a VS 1.7 m high to a grillage beam. The concrete surface in VS has a bias from the middle of the building to the surface of the surrounding territory. It provides lack of water and practically lack of snow in an underground and promotes its good cooling. Annual average air temperature in such underground on natural observations, was $T_p = -6.0 \, ^\circ C$. Out of a building zone boundary condition is set in the form of a sinusoid directly on the surface of soil. Annual average temperature of a surface is accepted to equal temperature in a zone of annual zero amplitudes taking into account "temperature shift". Distribution of temperatures on depth is set by results of calculation of a kvazistationary status. On the lower bound of an array the continuous temperature of $T_0 = -1.0 \, ^\circ C$ is set. On lateral surfaces of an array heat exchange is absent.

All array is presented by diverse horizontal layers of earth which thermophysics characteristics are defined depending on engineering-geological soil characteristics and temperature. Basic data are defined in relation to climatic and engineering-geological conditions on the construction site in citi Mirny. The estimated scheme of the frozen foundation of the building is submitted in figure 3.

![Figure 3. Estimated scheme of the frozen foundation of the building: 1 - ventilated air spaces; 2 – the heat insulation blind area; 3 – cold pile.](image)

At the first stage calculation was carried out from a condition that saving of a frozen status of soil is provided only VP. A temperature field of foundation of the building with the year-round open ventilated underground without additional cooling for the third year of operation it is presented in figure 4.

At the second stage of computational modeling the additional cooling elements in the form of SCD and a warm blind area were entered. Piles with thermosiphons were located on extreme axes of the building with a step of 1.5 m. In calculation only two piles on each extreme axis are considered. Temperature condition of fresh air is set in the form of a sinusoid with parameters $-7.6 \pm 28.0 \, ^\circ C$. As SCD a piles are accepted. Height of an elevated part of SCD of 1.5 m, and depth is lower than a day surface of 6 m.

Heat insulation thickness in a blind area during the experiment changed from 5 to 15 cm. As heater rigid extrusion polyfoam with coefficient of heat conductivity of 0.04 W/m $^\circ C$ was applied. Resistance to a heat transfer at a thickness of layer of 10 cm is equal to $R = 2.5 \, m^2 \, ^\circ C/W$ that is equivalent to snow thickness in 30-40 cm.
Figure 4. A temperature field of foundation of the building with the year-round open ventilated underground without additional cooling.

Calculation results are displayed for September when average temperature on the working length of a pile is minimum within a year. In figure 5 the temperature field created for the third year in foundation of the building with the year-round open ventilated underground, a heat insulating blind area and vertical SCD is presented.

Figure 5. A temperature field of foundation of the building for the third year of calculation with a heat-insulating blind area and the cooling SCD influence: 1 – blind area; 2 – SCD.

For further discussion we will note that bearing capacity of the pile bases set in frozen soil not linearly depends on negative soil temperature. The temperature is lower, the soil bearing capacity is higher.
3. Discussion and conclusions

Apparently from figure 4 edge zones have the reasons much more high temperature, than the average zone and, therefore, bearing capacity of piles in these zones is less, than in the middle of the building. The idea of uniform strength is broken.

It is offered to drop a temperature field under the building due to additional cooling in many works. Generally it is preservation of cold in the basis in the form of the device of seasonal heat insulation under all building [8]. Other way is an installation of additional vertical vapor-liquid SCD on building perimeter. Both of these sentences provide additional operating costs. Application of standard steel concrete piles with the built-in liquid thermosiphons is absolutely reliable and does not demand expenses at operation.

Apparently in the work area of extreme piles at a depth from 3 to 7 m make 2 – 2.5 °C of fig. of 4 soil temperature. The end face of an average pile is in a soil zone with a temperature of -3 °C. At additional cooling apparently from fig. 5 all piles both extreme, and averages are in close temperature conditions. The temperature field under the building is aligned on width. And negative soil temperatures in the second case are much lower, than in the first. Due to deep cooling by means of extreme piles there is a security zone promoting considerable fall of temperature of soil in a zone of average piles. The warm blind area saves cooling until the end of the warm period.

The executed computational modeling shows that additional cooling in the form of cold piles and a heat insulation blind area aligns a temperature field under the building. It allows to bring closer outside piles on bearing capacity to internal piles. Such solution increase reliability of constructions of the bases and do not demand additional operational expenses.

References
[1] Tsyiovich NA 1975 *The Mechanics of Frozen Ground* McGraw-Hill (New York)
[2] Velli YU and Dokuchaev V 1977 *Handbook of construction on permafrost soils* (Moscow: Stroyizdat) p 552
[3] Andersland B and Branko L 1994 *Frozen ground engineering* p 400
[4] Vaskovsky A P Shklyarov N D 1979 (Leningrad: Stroyiedat) p136
[5] Denderin I and Jakushevskij L 1982 *Housing Construction* 11 pp 8-11
[6] Goncharov U M 1982 *Housing Construction* 11 pp 12-13
[7] Kutvickaja N and Dashkov A 1983 *Problems of geocryology* pp 76-82
[8] Perreault P Shur Y 2016 *Cold regions science and technology* Vol 132, 11 pp 7-18
[9] Gamzaev R Kronik Y 2016 *V conference of geocryodens of Russia* MSU pp 245 – 252
[10] Dolgih G Okunev S and Strizhkov S 2012 *PNICP Salekhard* pp 153 - 159
[11] Passek V and other 2015 *Vestnik TjumGASU* 4 pp 43-46
[12] Kronik Y 2016 *V conference of geocryodens of Russia* pp 113-122
[13] Melnikov P, Makarov V and Plotnikov A 1981 *Eng. Geol.* pp 165-174
[14] Plotnikov A A Makarov V I 2017 *SMFE* 54(5) pp 341-348
[15] Makarov V 1985 *Thermosyphons in Northern Construction* (Novosibirsk: Stroyizdat) p 169
[16] Buchko N 2009 *Vestnik MAH* 2 pp 40-45
[17] Plotnikov A 1988 *Thermodynamic aspects of the mechanics of frozen soils* pp 86-94
[18] Kudryavtsev S 2004 *Soil Mechanics and Foundation Engineering* 41(5)
[19] Permjakov P Popov G and Varlamov S 2016 *V conference of geocryodens of Russia* p 286-291
[20] Fadeev A Saharov I and Repina P 1994 *Bases, foundations and soil mechanics* 5 pp 6-9
[21] Plotnikov A 2016 Industrial and civil construction 4 pp 62-67