Assignment of minimum depth of piled foundation in structurally unstable permafrost soils factoring in emergency situations

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Abstract. The set-out task is presented on the example of permafrost soils. Presented results show temperature regime calculations of the soil base of a building constructed according to 1 principle factoring in thermal effects of the underground collector, above-ground heat supply system and the emergency blow-out of high-temperature fluid from communications. Changes in the temperature regime of soils in the soil base of the building are assessed in the article. Article gives recommendations for assignment of minimum depth of piled foundations under presented conditions.

1. Introduction
Assignment of the minimum foundation depth in ordinary soils is largely determined by seasonal freezing depth. When construction is done on structurally unstable permafrost soils, starting point for assignment of the minimum foundation depth is set to estimated depth of seasonal thawing, which determines position of the upper boundary of permafrost soils. However, the position of the upper boundary of permafrost soils in dense urban areas depends not only on natural factors, but also on technological factors, in particular, thermal impact of above ground and underground utility systems and on emergency leaks from them. Especially significant is the impact on the soil base right in the vicinity of the utility connection to the building.

2. Literature review
According to current building design standards assignment of minimum foundation depth in permafrost soil base is measured from the upper boundary of permafrost soils, defined as the estimated depth of seasonal thawing, with an account for thermal effect of the structure [1]. This way, thermal effect of a building is accounted for only in its normal operating mode, and natural temperature regime is factored in excluding current and future climate change conditions of the planet. At the same time, construction experience on permafrost soils clearly shows that the major cause of accidents of industrial and civil structures is a local thawing of frozen soil bases and their subsidence during thawing as a result of exposure to heat effects from leaks from buildings or utilities[2-4]. This is evidenced by the Federal Agency of state statistics service in the Republic of Sakha (Yakutia) which notes high proportion of dilapidated buildings, with a share of 16.5% in 2016, of the total number of permanent buildings Built on the territory of the Republic [5].
It is obvious that consideration of factors that influence formation of temperature regime of permafrost soils will allow more reliable prediction of the temperature distribution and, based on the results, position of the upper boundary of permafrost soils. Accidental leakage from utilities is significant and difficult to predict factor influencing the temperature regime of soil bases of buildings and structures in permafrost soils. Thermal effects, caused by such accidents on thermal stress-strain state of soil bases, negatively affect operational reliability of buildings on permafrost. [6-10].

The situation is aggravated by the trend of the last 50-60 years on planet climate warming. Together with anthropogenic factors, first and foremost, with emergency blow-outs from heat-supply networks and sewage systems, modern climate situation contributes to the degradation of permafrost strata in general and in built up areas specifically. [11-15] Considering that the upper boundary of permafrost soils is factually a thermal blow-out of the temperature of start of freezing of soils, it is necessary to forecast the temperature regime of the soil base under the influence of various factors of natural and technogenic origin.

3. Materials and methods

As a calculation tool software package Frost 3D was selected, allowing us to get scientifically based predictions of thermal conditions of permafrost soils in factoring in technogenic effect of additional temporary and permanent sources of thermal emissions which significantly affect formation of thermal fields of frozen soils. The calculation algorithm is based on an enthalpy model in which freezing temperature of gravity and bound water and temperature of practically frozen soil are not constant, but are generally variable, depending on the type of soil, its properties: moisture, density, applied pressure, concentration of detached water and freezing rate.

The solution to the heat-transfer equation in three-dimensional formulation is implemented numerically using the finite difference method. This method is a grid, i.e. the computational domain is discretized with hexahedral mesh, and the solution directly to the mesh nodes, each of which has differential equation in accordance with used pattern of the difference scheme. A system of linear equations is obtained, solution of which allows us to obtain necessary result in the considered computational domain.

Design scheme is homogeneous frozen soil strata as the base of the building constructed by the 1st principle (Fig. 1). Dimensions of the building in plan are 30 m by 24 m, building height is 10 m, height of the vented crawl space is 1.2 m. Soil base strata is homogeneous, presented by a sand of medium size, thickness of the strata is 30 m. Thermal characteristics of the soil are taken as an average values typical for the Central part of Yakutia. The initial data for the average value was taken from selective results of geotechnical surveys performed for various buildings over the past 20 years. Climatic parameters taken from SP 131.13330-2012 "Construction climatology"[16] for the city of Yakutsk. Each simulated object had specified geometric shape and size, boundary temperatures, thermophysical properties and heat transfer conditions on the surfaces. Additionally, formation of the temperature regime of the soil strata is influenced by buried collector, and the inlet high temperature piping.
Figure 1. Calculation scheme of the task, where: 1 – Building constructed according to 1st principle; 2 – vented crawl space, 3 – inlet high temperature piping; 4 – buried collector, 5 – soil base of the building laid from permafrost soils.

At the first stage, a calculated temperature distribution field was formed in the soil base strata under normal operating conditions, that is, without factoring in influence of additional emergency factors. This thermal field is the initial temperature distribution for tasks to factor in accidental leaks and is the baseline for comparison and assessment of the influence of additional factors on the frozen soil base thermal field.

The influence of accidental leakage on the temperature regime is modeled by a temporary temperature stamp, size, location, temperature and duration of which is assigned according to the situation as suggested by M. Rabinovich and Ya. Kronik [4]. In this work, we studied the effect of three independent stamps simulating accidental high-temperature (+ 60 °C) leaks: under the bottom of the collector, under the heating pipe between the collector and the edge of the building and directly below the building. We calculated temperature fields from each of these stamps separately and in combination. For correct comparison of all calculation options were applied at the same time (March 16) and control sections of the temperature fields were taken every 30 days for three months.

4. Results of the research
To obtain the results of the study, 3 problems were solved with a different arrangement of accidental leaks relative to the building. As a result, the task to forecast the temperature regime of the soil base of a building for 3 months during exposure to heat from a buried collector, above-ground utilities and short-term (and temporary) local and linear leaks is formulated and solved. With the help of software complex Frost, we visualized 3D view of thermal field of soil and the graphical dependence of temperature change from coordinates and time.

As an example of the obtained results, in Fig. 2 and Fig.3 we can see thermal fields at the time of removal of heat load and three months after the effects of heat stamp under the heat-supply system and directly under the building.
Figure 2. Temperature distribution of permafrost soils at the time of removal of the heat load from accidental leaks under the pipe of the heat-supply system and under the building.

Figure 3. Temperature distribution of permafrost soils three months after removal of the heat load from accidental leaks under the heat-supply pipe and under the building.
In the first task, we assume that the leak (temperature stamp) is located under the collector. To analyze the results, it is necessary to choose a section in which the difference in the distribution of temperature fields and the degree of influence of the stamp on permafrost soils will be visible. Let's select a section along the pipeline and the collector along the axis of the pipe.

The temperature distribution graphs show that at the beginning of the accident, temperature on the collector surface reaches 38 degrees. For a given distance of 6m between the building and the buried collector, there was almost no thermal effect on the soil base detected from leakage in the collector. Three months later, temperature stabilizes and equals to 7 degrees, which practically corresponds to the initial temperature distribution, therefore, temperature regime restoration process from a single accidental leak is completed.

Another situation was revealed by analyzing the results of exposure to temperature stamps applied along the heat-supply system and directly under the building (Fig. 2 and Fig.3). After three months, there remains a noticeable distortion of soil temperatures distribution under the edge of the building. We especially note that the position of the upper boundary of permafrost soils has significantly changed in the first month after removing the heat load from the leak.

Obtained numerical calculation data shows that factoring even a single accidental leak leads to an increase in the temperature of the soil of the base to a depth of 2.5 meters from the surface of the heat stamp application. At the same time, the position of the boundary between thawed and frozen zones decreases by 0.6 m.

Given the situation, SP 25.13330.2016 [1] assigns minimum piled foundation dept based on the upper boundary of permafrost soils, calculated as the depth of seasonal thawing according to annex G. According to this annex, position of the upper boundary of permafrost soils is formed under the influence of natural factors factoring in thermal effect of the structure in normal operation.

5. Conclusions
The results of numerical calculations of the temperature distribution in permafrost soil bases give us reason to argue that factoring in anthropogenic accidental influences has a significant effect on frozen soil bases and requires consideration when assigning minimum foundation depth and calculating bearing capacity of the foundations of buildings and structures.

Calculations have shown that the position of the upper boundary of permafrost soils is affected by the thermal effect of accidental leaks, therefore, it is necessary to revise either the principle of assigning the minimum foundation depth or its parameters. It takes a lot of time to develop new approach, at the first stage it would be advisable to assign a minimum foundation depth in frozen soils to 0.5 meters more than what is now provisioned in SP.

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