Thermal-physical calculations as a basis of design solutions of buildings and structures in the permafrost zone

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Abstract. The goal of calculations in foundation engineering is to define strain-stress behavior of a soil bulk due to loads transferred from a structure to a subsoil. While calculating subsoils of foundations, which consist of frozen and permafrost soils occupying about two thirds of the territory of Russia, an engineer should firstly predict changes of temperature fields in the subsoils. These calculations imply that a future expert is aware of equations of mathematical physics, boundary conditions of temperature problems etc. However, thermal physics is not included in the curriculum of university departments, which train specialists making calculations or design of foundations. Due to this fact, as a rule, a university graduate lacks knowledge on the laws of thermal distribution in milieus and on the methods of solving the corresponding problems. The paper gives a number of examples of thermal-technical calculations of foundations subgrades, which show the necessity of knowledge in the field of thermal physics during design of structures in the permafrost zone.

1 Introduction

The goal of calculations in foundation engineering is to define strain-stress behavior of a soil bulk due to loads transferred from a structure to a subsoil. The university curriculum in the field of civil engineering includes the mandatory subject of soil mechanics. Therefore, a future engineer is usually well aware of the laws of stress distribution in a bulk of Boussinesq, Flamant, Mitchell etc. Stress contours in a soil bulk caused by action of various loads as well as stress curves are widely used in calculations of settlement, therefore, constituting intrinsic knowledge of a young specialist.

While calculating subsoils of foundations, which consist of frozen and permafrost soils occupying about two thirds of the territory of Russia, an engineer should firstly predict changes of temperature fields in the subsoils, that implies the solution of thermal-physical problems and the analysis of calculation results. These calculations imply that a future expert is aware of equations of mathematical physics, boundary conditions of temperature problems etc. However, thermal physics is not included in the curriculum of university

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departments, which train specialists making calculations or design of foundations. Due to this fact, as a rule, a university graduate lacks knowledge on the laws of thermal distribution in milieus and on the methods of solving the corresponding problems. One should also add that flat and spatial thermal problems, which include layers of soils, concrete, thermal insulation, various in their thermal-physical properties, as well as temperature conditions, which change thermally in time, indispensably require application of numerical methods of problem solutions. Therefore, a graduate from a Russian university has no understanding about even approximate results of calculations. It largely complicates the simplest control of solution of thermal-physical problems and reduces confidence of an engineer making calculations in the obtained results, in particular, it relates to permafrost soils, which vary in composition and temperature parameters.

Therefore, specialists should use well-proven and tested software in their thermal calculations. In case of using correct input data a reliable software can make a correct solution, although sometimes the received results seemingly contradict a preliminary prediction. Below there are some examples of solving the problems, which main feature is the thermal-physical component. To solve these problems we used the software "Termoground", which is renowned in the international practice, its principles and features are described in [1-4].

2 Example 1. Loss of stability of strutted sheet piling of excavation walls during freezing of soils

Strutted sheet piling of a wide 12-m-deep pit lost stability at the end of a winter period (fig. 1).

Fig. 1. Loss of stability of strutted sheet piling.

Calculations of pit fencing were made for active soil pressure caused by its dead load and a temporary load on the surface. However, the loss of stability of short struts shows that horizontal pressures applied to fences considerably exceeded the calculated ones.

 https://doi.org/10.1051/matecconf/201926505009

In order to understand causes of this phenomenon let consider a problem of freezing and heaving of soil located in the rear side of the sheet pile wall (fig. 2-4).

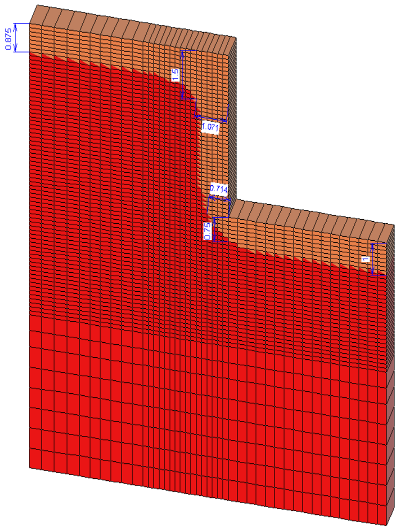

Fig. 2. The contour of frozen soil around the excavation.

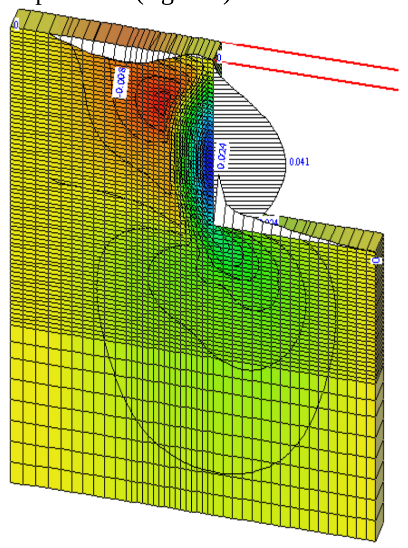

Fig. 3. The curves of horizontal displacements of the wall.

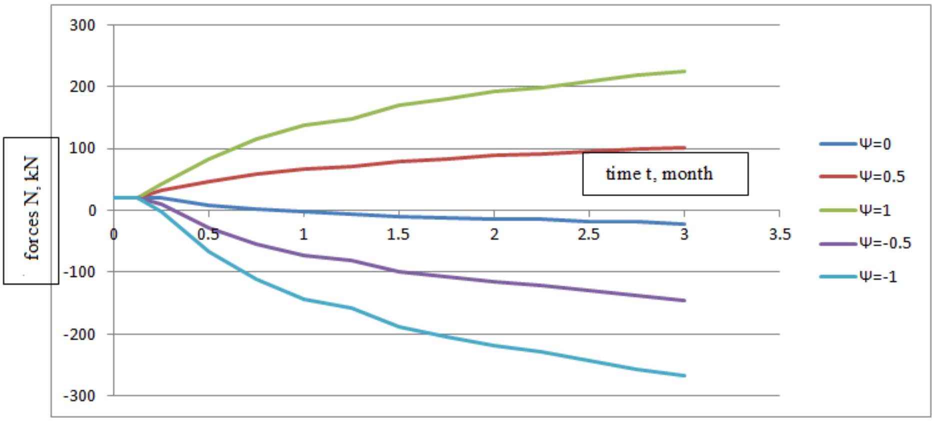

Fig. 4. The values of forces in a strut during soil freezing depending on a coefficient of anisotropy.

Based on the results of the thermal problem solution fig. 2 shows an area of frozen soil along the contour of excavation. It is noteworthy that the thickness of the frozen layer in the location of strut installation, i.e. close to the surface, is twice as large as the thickness of freezing in the lower corner of the pit (1.5 and 0.75 m, respectively). The maximum horizontal displacements of the wall are also connected with the location of strut installation (fig 3). The calculations show that forces in the strut change depending on time and ability of soil to deform in different directions at freezing (depending on so-called coefficient of anisotropy). In the worst case scenario forces in the strut can increase several times compared to the calculation without soil freezing (fig. 4). This example proves that one should not ignore cryogenic processes dealing with temporary structures, which operate in winter.

3 Example 2. Settlements of pile foundations during thawing of frozen soils

Pile foundations of a frame building in the north suffered a large settlement. Only 6 out of 80 pile groups settled. The maximum settlement of one of pile groups reached almost 20 cm, meanwhile the adjacent pile groups almost avoid deformation. This considerable differential settlement, which reached 0.018, resulted in destruction of joints of steel bars of floors and caused the risk of their failure.

In order to define causes of these differential settlements the history of the facility construction has been studied. Special attention was paid to the building orientation towards the cardinal points, hence, it was found out that the settled piled rafts were located in the northern shadowed part of the building. The solution of the temperature problem showed that a depth of soil freezing in the northern part of the building, including the basement, is considerably larger than in the rest of the facility, that resulted in larger settlements of thawing. The calculation scheme of the problem and the graphs of settlements of pile groups are given in fig. 5 and 6. As it can be seen in fig. 6, these are piled rafts in the northern part of the building (points 4 – 9) that suffer from the largest settlement, while points 1-3 not subjected to freezing and thawing of soil are almost immovable.

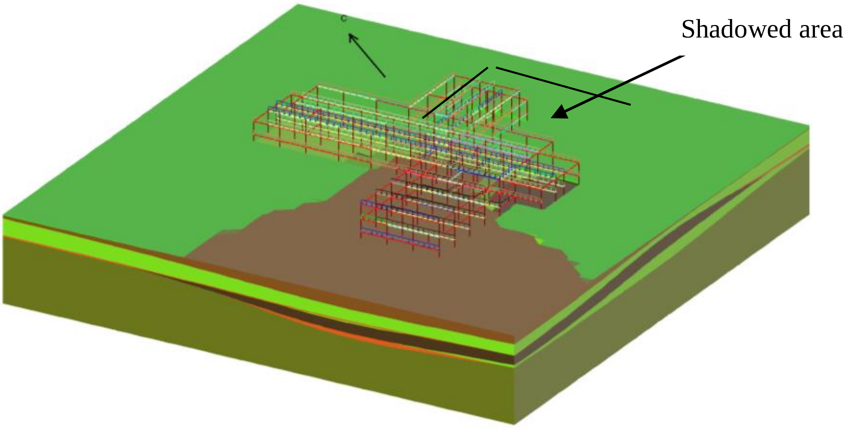

Fig. 5. Calculation scheme of the problem.

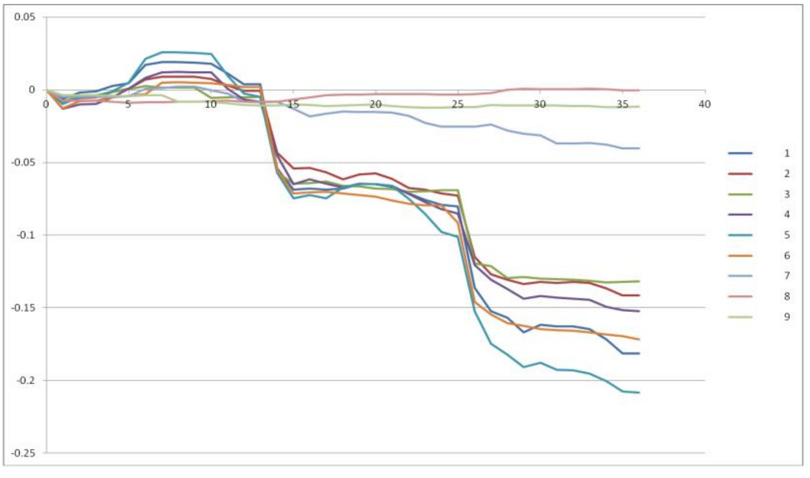

Fig. 6. Development of settlements of piled rafts in time.

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In the case under consideration only the solution of the temperature problem allowed to define a real problem of catastrophic settlements of pile foundations located in the shadowed part of the building.

4 Example 3. Development of a thawed zone in the filling of the pier wall designed according to principle I

The pier wall of a northern port was designed preserving the frozen state of subsoil, i.e. according to principle I (fig. 7).

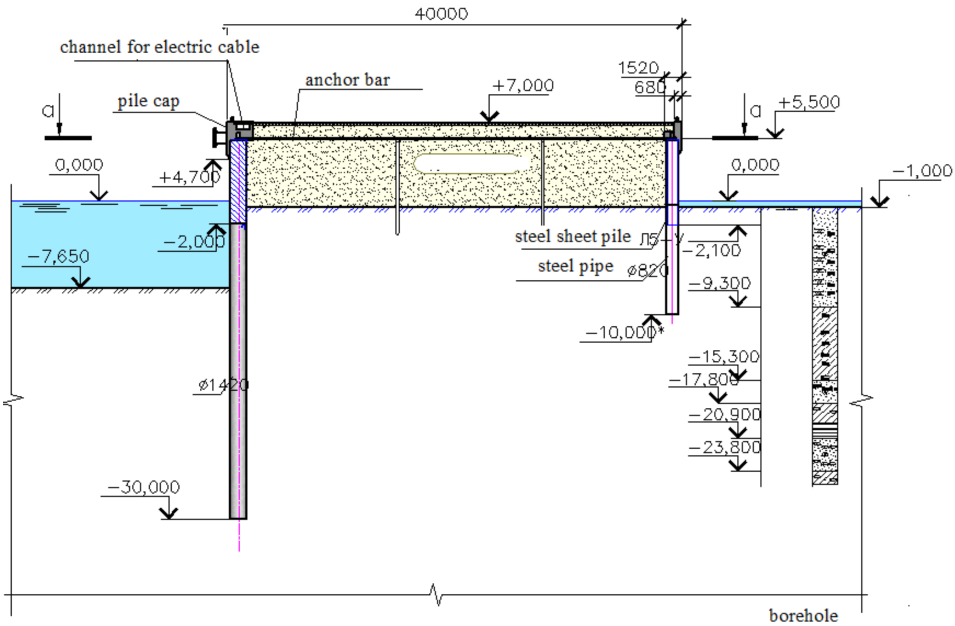

Fig. 7. The design solution of the pier.

Natural stratification of soils in the area of pier construction is rather complex (fig. 8).

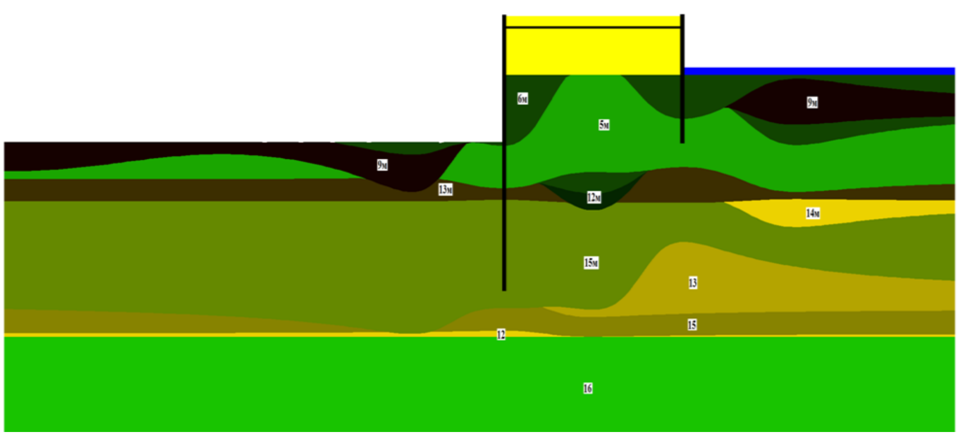

Fig. 8. Natural stratification of soils in the area of pile construction.

Due to all-year-round operation of the pier in this case it is necessary to consider permanent water presense from the front side of the wall, that implies existence of a thawed zone in the rear part of the pier. The solution of the temperature problems shows that the sizes of the thawed zone are rather big and they should be considered at calculation of active pressure of soil applied to the wall (fig. 9). It is also noteworthy that due to constant movement of sea transport and temporary storage elimination of the thawed zone behind the wall, for example, with a help of installation of thermal syphons, appears to be impossible.

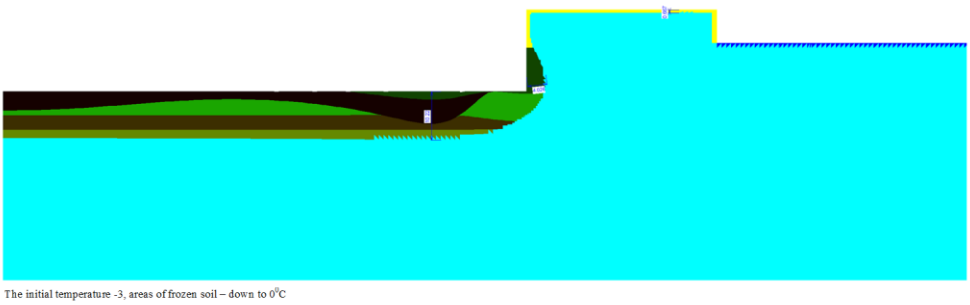

Fig. 8. Development of the thawed zone in the seabed and in the rear part of the wall (numbers show sizes in m).

5 Example 4. Thermal stabilization of the highway subgrade

A solution on thermal stabilization of the highway subgrade on the frozen soils in Chita region implied strengthening of the plastic frozen subgrade with a help of thermal stabilizers (fig. 9).

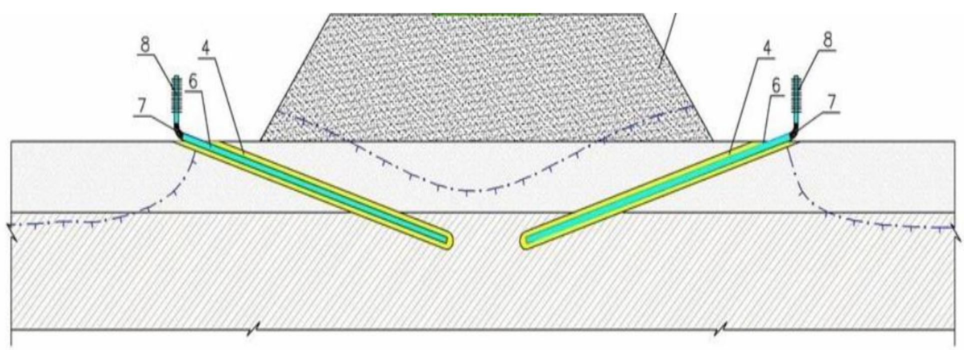

Fig. 9. Inclined thermal stabilizers in the subgrade of a highway embankment (6 – thermal stabilizer with condensor 8).

According to the authors of the solution, thermal stabilization increases strength and stability of the subgrade and guarantees its stability during seasonal thawing. However, the solution of the thermal physical problem showed that inclined thermal stabilizers encorage development of clozed zones in the subsoil, in which areas of high pore pressure emerge during freezing. During further freezing of these areas soil breakthroughs under the increasing water pressure together with failure of the embankment and forming icing are inevitable (fig. 10). It means that in this case the use of inclined thermal stabilizers is evidently non-advisable.

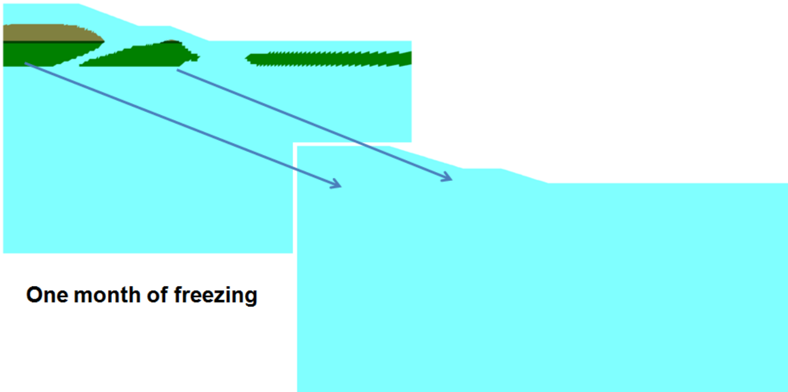

Fig. 10. Closing of thawed zones during freezing (January – February).

6 Conclusions

1. Buildings and structures in the permafrost zone have joint thermal and force impact on the subsoil.
2. The equations of thermal dynamics, including energy of thermal impact and deformation, still do not have strict solutions, therefore, real problems allow separate consideration of thermal and mechanical processes.
3. The presence of permafrost and freezing soils requires paramount thermal-physical analysis in the “soil-structure” system, which is frequently a defining factor to select an adequate design solution.

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