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Investigation of the construction of airfield pavement using extruded polystyrene foam in the cold regions of the Russian Far East

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Abstract. The paper presents the results of scientific research and engineering calculations of rational designs parameters of airfield cover for cold regions of Russia using airstrip in Yuzhno-Sakhalinsk airport as the example. This airport is located in severe climatic and complex engineering-geological conditions. A deep seasonal freezing occurs everywhere. Applying extruded polystyrene plates in the structure construction makes it possible to significantly reduce frost heave and reduce foundation deformation. Performing numerical modeling of structures using «FEM models» geotechnical software complex allowed to quantify the processes of freezing and thawing in the annual cycle for the construction conditions. Based on the research results, designed constructive measures to ensure the operational reliability of the proposed rational engineering solutions for airstrips in the northern territories of the Russian Far East.

1 Introduction

Development is a solution range of engineering, scientific and settlement-applied tasks. The work purpose is to obtain a rational design of an airstrip cover using modern technologies and advanced materials provides the required parameters for bearing capacity and operational reliability in complex engineering-geological and severe climatic conditions in the northern territories of Russia [1,2].

Experimental research were conducted in the experimental section equipped with temperature sensors installed in the test sections at various depths of freezing under normal conditions and using extruded polystyrene foam. whole construction and the traffic safety on the deformed section until the active measures work in full (Fig.1, 2). Development Conducted over the past two years research course data showed a stabilization of the temperature regime in the area of using extruded polystyrene plates.

Experimental To confirm the experimental research requires a joint evaluation of thermal and stress-strain state of soil in the freezing-thawing process.

In achieving the goals and tasks performed geotechnical numerical simulation of the stress-strain state under the loads and thermodynamic processes during freezing-thawing in an annual cycle for designs options of airfield landing strips foundation.

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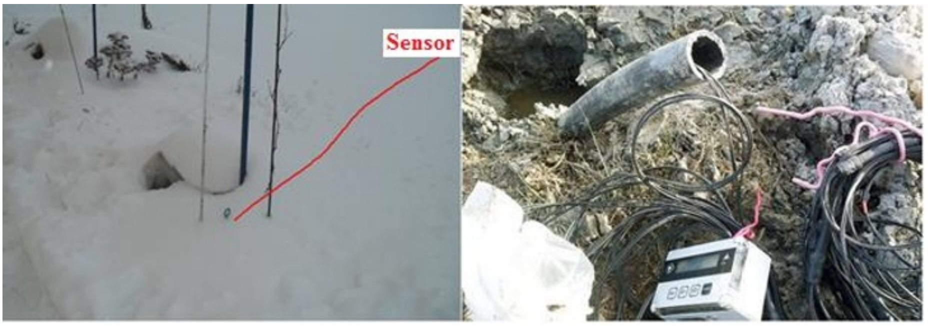

Fig. 1. Sensor №1, rock-hole.

2 Methods of numerical modeling

2.1 Method of numerical modelling of stress-strain state

The design geotechnical modeling was performed using software package «FEM models», which was developed by geotechnical engineers from Saint-Petersburg.

The elastic-plastic model with the yield criterion was used to describe the work of variable stiffness design. This elastic-plastic model was chosen because its parameters can be taken from existing material of engineering and geological surveys.

Numerical methods are in good correspondence with the traditional engineering methods of calculating the settlement in such formulation. They provide accurate description of deformations in structures [3].

Figure 2 shows a scheme of determining the theoretical stresses in the elastic-plastic model of the soil.

The ultimate stresses in the tension field are restricted by the tensile strength σ_p.

Area I in the tension field is restricted by the stress $\sigma_3=\sigma_p$, while in the compression area it is restricted by the Coulomb strength criterion according to:

$$\sigma_1 = R_c + \sigma_3 ctg\psi \tag{1}$$

where *Rc* is the uniaxial compression strength.

The element stiffness matrixes and the ones for the whole system are formed once and stay the same in the procedure of elastic-plastic solution. The load is applied in small portions as it happens in its real sequence in nature.

If the point *M* occurs within the limits of the elastic region I, it means the element is in the elastic state and there is no need to correct the stresses.

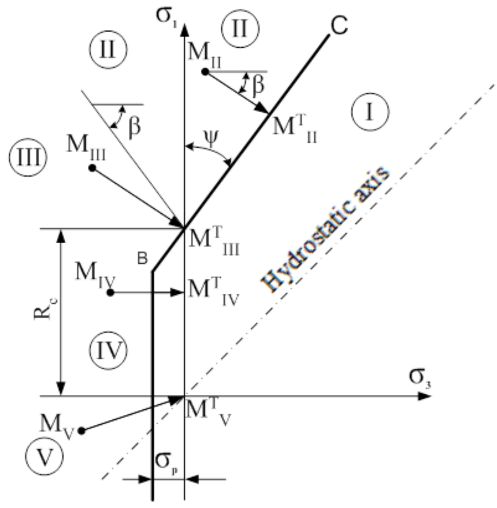

Fig. 2. Scheme of determining theoretical scheme stresses in elastic-plastic model of soil.

If the point *M* occurs beyond the yield behavior contour, the theoretical stresses are calculated in the following order. If the point of total stress occurs in the area II (the basic plastic zone), the theoretical point lies at the intersection of the plastic yield and the right line.

If the point of total strength occurs in area III, the element breaks in the direction of the stress, while the stresses go down to the level of the soil strength to the uniaxial compression.

The area IV where the stresses do not go beyond the uniaxial compression strength. Finally, the area V where the element is broken.

In the «FEM Models» program, the natural stress state is substituted by the hydro engineering tensor for pressing the soil of the «characteristic volume» that is summarized with the actual stresses in situ:

$$\{\sigma_{1,3}\} = \{\sigma_{1,3}^F\} + \{\sigma_{1,3}^G\} \tag{2}$$

The assumption reflects a real picture of the natural stress state in weak soils.

The used method and the software package «FEM models» are developed by the authors for the projects under construction in Russia and the Far East.

Application of the methods and approaches for the calculation and design of geotechnical structures using software package «FEM models» show its accurate and objective performance in the most rational calculations of geotechnical constructions.

2.2 Method of numerical modelling of stress-strain state

Investigation of the processes of freezing and thawing of the soil base of the thermopiles foundation is expedient to carry out the methods of numerical simulation.

Numerical simulation of the thermopile foundation in permafrost performed in the software package «FEM-models», developed by Geotechnics St. Petersburg under Professor V.M.Ulitskogo. Integral part of «FEM-models» is a program «Termoground», which allows you to explore with the help of numerical simulation in the spatial setting processes of freezing, frost heaving and thawing in the annual cycle of the finite element method [4].

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

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

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 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.

3 Results of numerical simulation

Solving thermophysical problems for rational design in predetermined operating conditions, a mathematical model «Termoground» was used to numerical simulation of freezing, frost heave and thawing processes in the annual cycle [5,6]. The model is an integral part of the «FEM-models» software complex. The solution involves counting the water phase transformations in the range of negative temperatures, as well as the presence of moisture in the freezing zone of the soil displaced by the migration toward the freezing front. Figure 3 shows the design scheme of the engineering-geological section of the airfield cover without a heater and with extruded polystyrene plates.

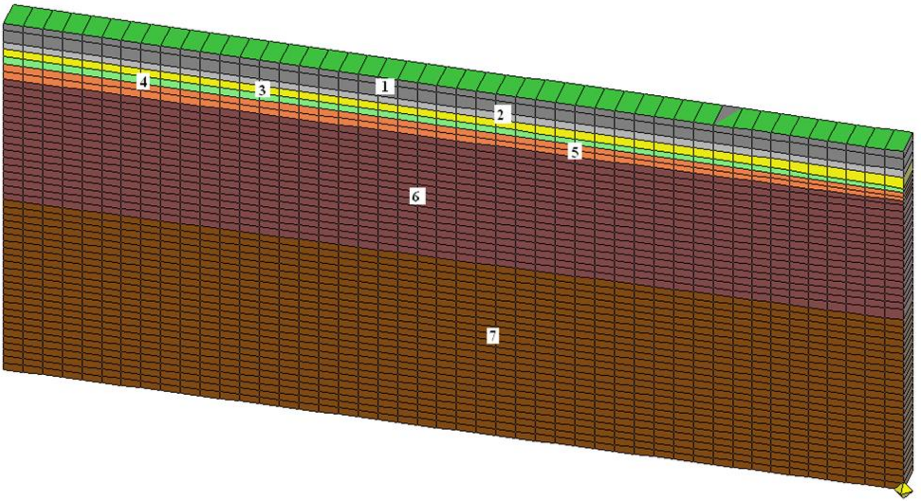

Fig. 3. Calculation scheme of the engineering-geological section of the airfield cover with the use of anti-heave measures (without/with extruded polystyrene plates): 1 – concrete; 2 – sand cement; 3 – leveling sand filling; 4. – extruded polystyrene; 4 – gravelly sand with interlayers of large sand; 5 – pebble soil with sandy loam up to 30%; 6 – medium-dense gravel soil with sandy loam up to 45%.

Figures 4, 5 show temperature distribution diagrams in the construction of an airfield cover without a heater and with thermal insulation of extruded polystyrene plates as of March.

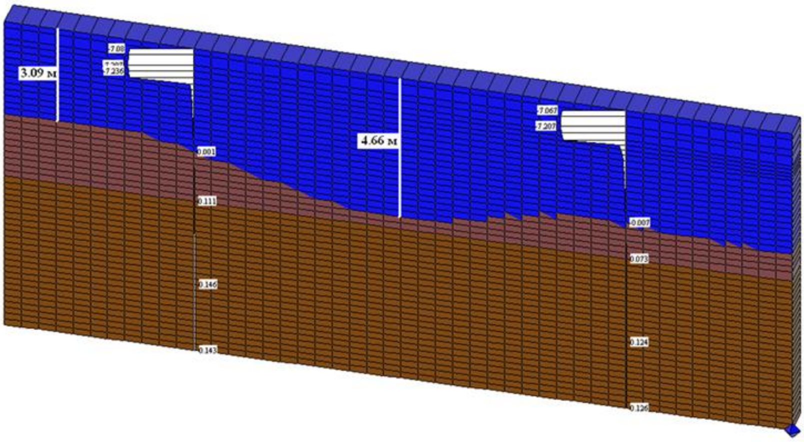

Fig. 4. Temperature distribution diagram in depth in the construction without anti-heave measures as of March (without extruded polystyrene plates).

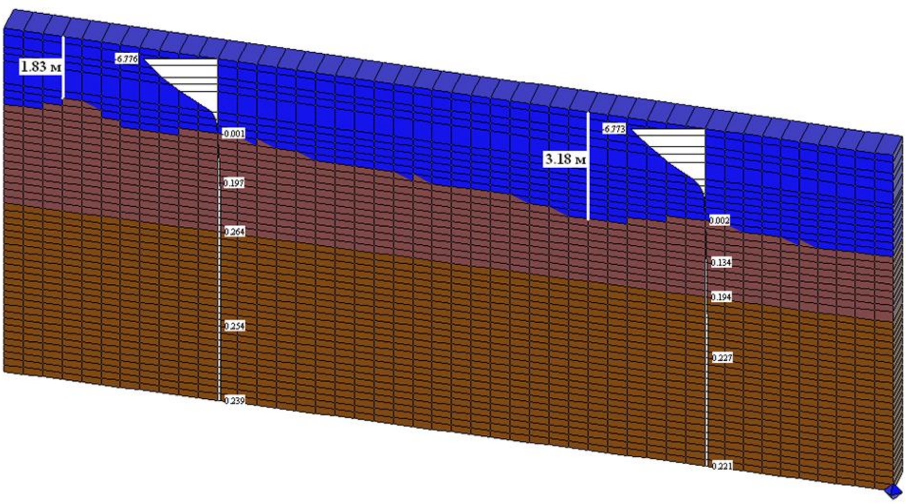

Fig. 5. Temperature distribution diagram in depth in the construction with anti-heave measures as of March (with extruded polystyrene plates).

To determine the values of frost heaving and thawing of an airstrip concrete covering surface in the annual cycle, an elastoplastic model with a limiting surface was used, the initial data was taken from standard geotechnical investigations materials. Numerical simulation was made of the stress-strain state of the structures of the aerodrome coating without anti-heave measures and with installation of expanded polystyrene insulation (Fig.6.).

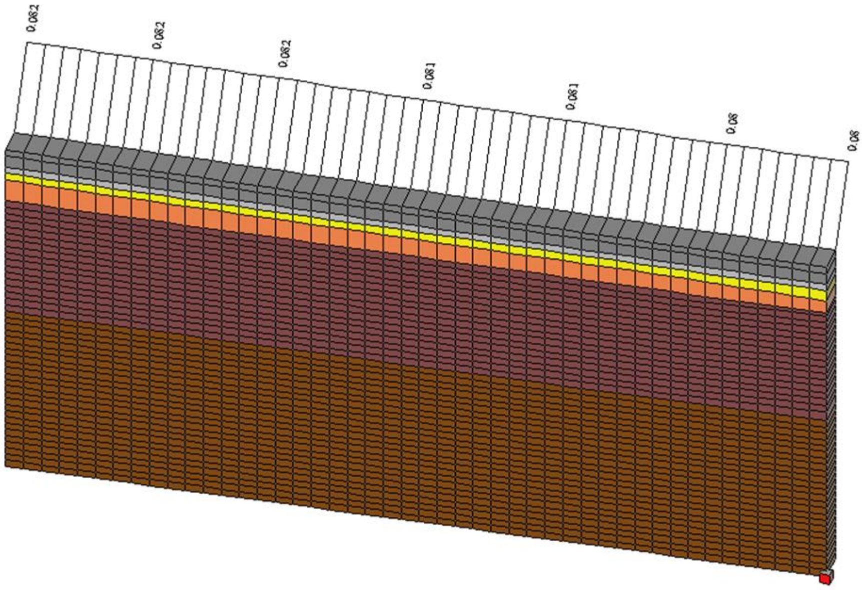

Fig. 6. Vertical stresses diagram of an airstrip concrete surface without a heater in March, kPa.

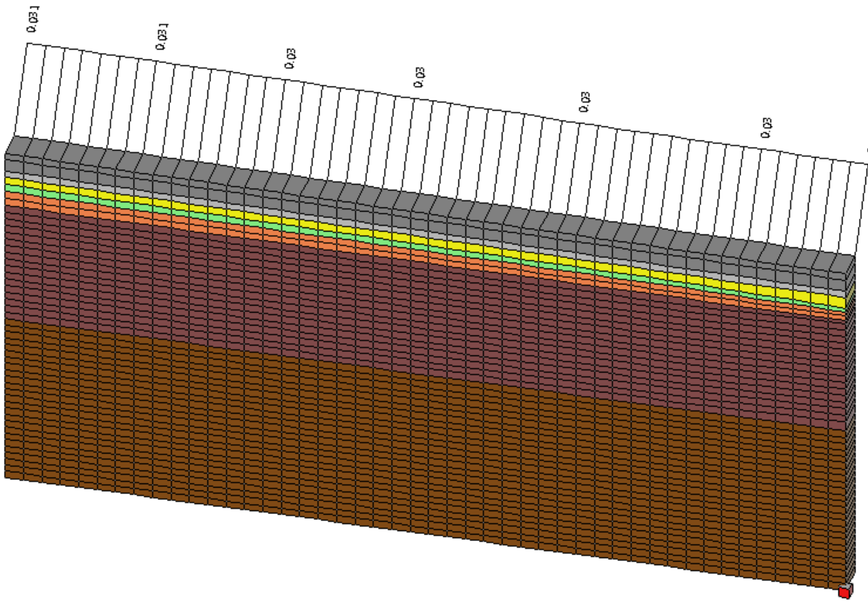

Fig. 7. Vertical stresses diagram of an airstrip concrete surface with installation of expanded polystyrene insulation in March, kPa.

Figure 8 shows temperature distribution graphs of the airstrip concrete covering sole in the annual cycle without a heater and with installation of expanded polystyrene insulation.

After statistical processing the obtained measurement results were used for comparative analysis with calculated numerical modeling data. The analysis results showed their good convergence. The boundary of negative temperatures in section with extruded polystyrene plates in use has shifted to the surface of the ground [7,8]. Currently ongoing monitoring of temperature conditions on the established temperature sensors (Figure 4, 5).

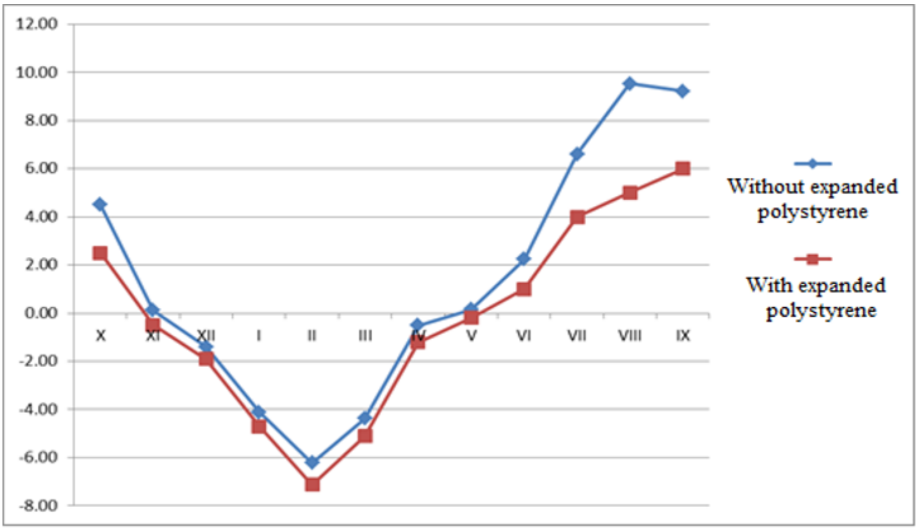

Fig. 8. Vertical stresses diagram of an airstrip concrete surface without a heater in March, kPa.

4 Conclusions

1. The results of experimental research have shown the temperature regime stabilization of the airfield cover base soil using expanded polystyrene plates.
2. The calculated values of frost heave deformations for the annual cycle in a design with thermal insulation are no more than 70% of normative values equal to 30 mm.
3. Geotechnical modeling found that elastic deformations magnitude in the developed rational design do not exceed the required values for materials and structures generally equal to 21 mm.
4. The temperature values measured in the experimental section, showed good convergence with the calculated values obtained by numerical simulation of the structure, which indicates the reliability of theoretical assumptions made for research
5. Complex research performed in the design of the airfield cover using extruded polystyrene showed the operational reliability of its elements for use in the cold regions of the Russian Far East.

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