

# Investigation of light embankment on weak soils

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**Abstract.** This article describes a technology for the construction of light embankments with an explanation of the scope of use, the constituent materials and key advantages

## 1 Introduction

One of the main problem in Russia is building a high-quality developed road infrastructure is the natural-climatic factor. There is a need to build roads, interchanges and bridges in a zone of unstable soils: in coastal regions and swampy terrain with weak soils, in areas with high groundwater table, zones of seasonally frozen and permafrost soils.

Process of a building a strong and durable road is a complex and expensive task. Solution of this problem is in applying the latest technologies which using advanced materials. The idea include using as a soil the body of the embankment not a sand-gravel mixture or other natural materials, but special hydro-heat-insulating materials that not only provide protection against the damaging effects of water and other corrosive environments, but also reduce the cost and term of road construction, with an increase in the guaranteed period of accident-free operation [1-6]. An important and promising sphere of road construction is the erection of light embankments from blocks of extruded polystyrene in the construction of roads and other engineering structures on a weak basis (Fig. 1).



**Fig. 1.** The erection of a light embankment on a weak base

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The light embankments called bases, which, with the same geometric dimensions, have a much smaller specific gravity, coming to  $1\text{m}^3$  of the embankment, due to the content of materials having a significantly lower specific gravity compared to the ground. It reduce the pressure of the embankment from its own weight to the base, which makes it possible to erect a light embankment without additional measures to strengthen the soil. As a material of a body we use blocks from the extruded polystyrene, created by application of extrusion to polystyrene of general purpose are used.

The purpose of this work was to calculate the second line of the railway tracks and to identify the impact of already existing degraded soils on the structure.

## 2 Calculation of the load bearing capacity of the pipeline ground

Calculation of the load bearing capacity of the pipeline ground made on the basis of SR 25.13330.2012 "Soil bases and foundations on permafrost soils".

### 2.1 Methods of numerical modeling

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 [7-10].

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.

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  $\sigma_p$ . 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:

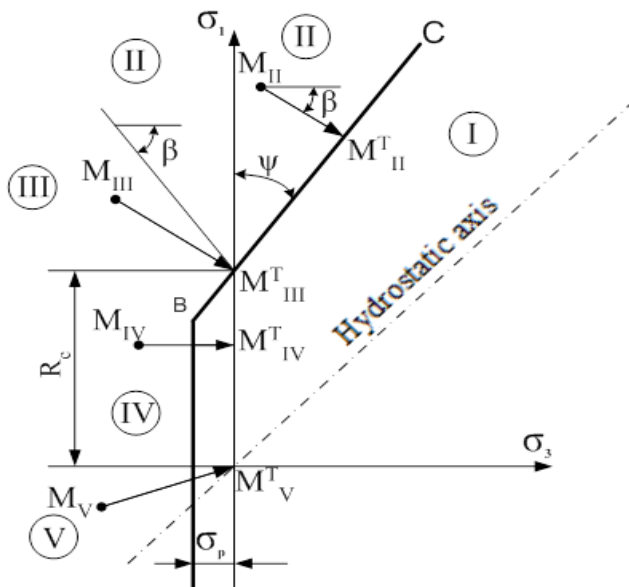
$$\sigma_1 = R_c + \sigma_3 \text{ctg} \psi \quad (1)$$

where  $R_c$  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.

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.



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

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:

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

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.

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.Ulitskii. 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.

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

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

where  $C_{th(f)}$  - specific heat of soils (frozen or thawed), J/kgK;  $\rho$  - soil consistency, kg/m<sup>3</sup>;

$T$  - temperature, K;  $t$  - time, c;  $\lambda_{th(f)}$  - thermal conductivity of soil (frozen and thawed), W/mK;  $x, y, z$  - coordinates, m;  $qv$ - internal heat source capacity, W/m<sup>3</sup>.

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:

$$T_{pr} = T_b + \Delta t_r - \Delta t_e \quad (4)$$

where  $T_b$  is average monthly air temperature, °C;  $\Delta t_r$  and  $\Delta t_e$  are corrections to average monthly air temperatures due to solar radiation and evaporation, °C.

The correction to air temperature due to solar radiation ( $\Delta t$ ) is calculated according to formula:

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

where  $R$  is monthly sum of radiation balance for the considered element of the surface, kkal/sm<sup>2</sup>·months;  $\alpha$  is surface heat exchange coefficient, kkal/m<sup>2</sup>·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:

$$R_o = Q_o \times k - 0.42 \quad (7)$$

where  $Q_o$  is average monthly sum of total solar radiation striking the horizontal surface, kkal/sm<sup>2</sup>·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:

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

where  $I_o$  and  $D_o$  – average monthly sums of direct and diffuse radiations striking the horizontal surface, kkal/sm<sup>2</sup>·months, the values being taken from the climatological guide;  $m_\beta$  – nondimensional coefficient in terms of the bevel face angle to horizon and spatiolization of the face for beam radiation intake.

$P_\beta$  – 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:

$$P_\beta = \cos^2 \frac{\beta}{2} \quad (9)$$

where  $\beta$  – angle of the bevel face to the horizon, degrees.

The thermophysical 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;  $\delta_{ith}$  is the relative strain of thaw loading subsidence.

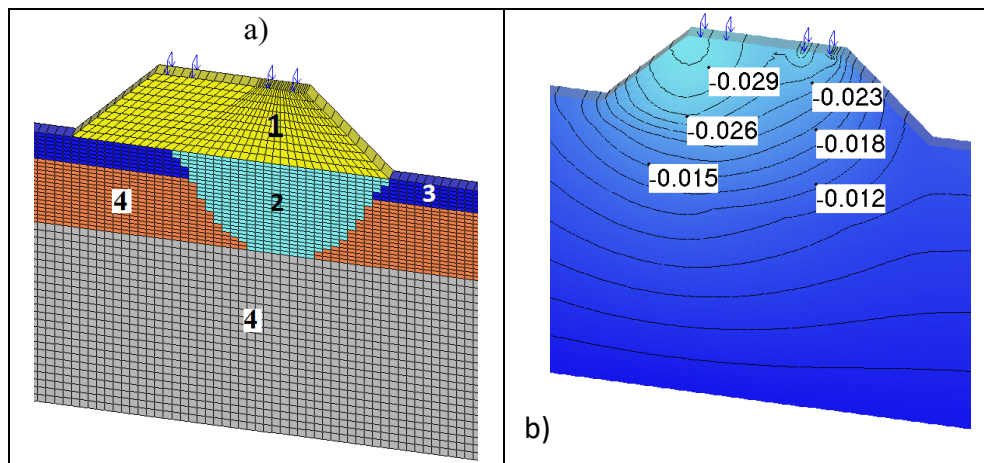
$$\delta_{ith} = m_{0th} \cdot P_i \tag{11}$$

where  $m_{0th}$  is the coefficient of compressibility of thaw soil (MPa<sup>-1</sup>);  $P_i$  is the compacting vertical stress (MPa).

### 2.2 Calculation results

The engineering-geological conditions of the rail embankment of the Baikal-Amurskaya Highway on permafrost grounds were chosen as research. A model of the second railway tracks was designed in conjunction with the existing railway line, taking into account degraded soils for 1 year after the embankment was built using light embankment technology and without.

In Fig. 3 shows the calculation scheme (a) and the results of calculating the vertical deformations of the elastoplastic solution (b).

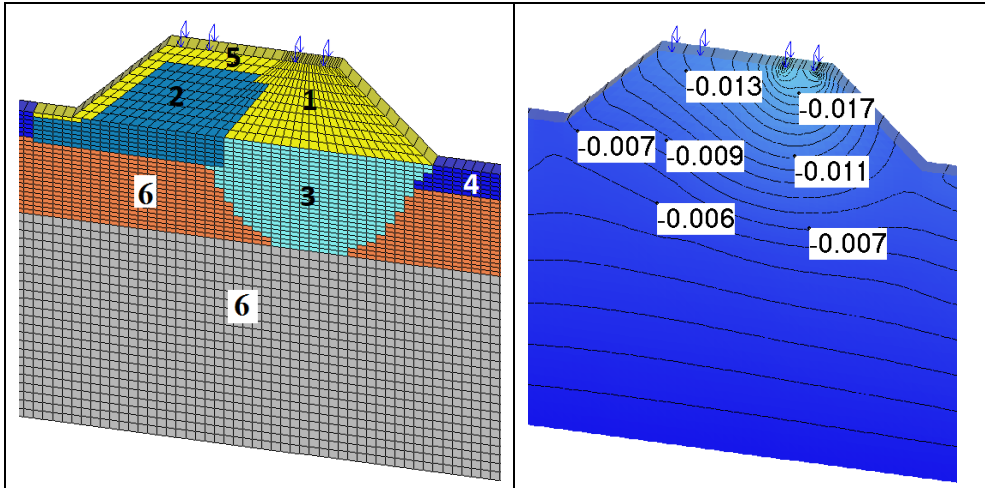


**Fig. 3.** The settlement scheme of embankment construction of the second tracks.  
 1- soil embankment, 2 - melt soil, 3 - seasonally freezing soil, 4 - frozen soil

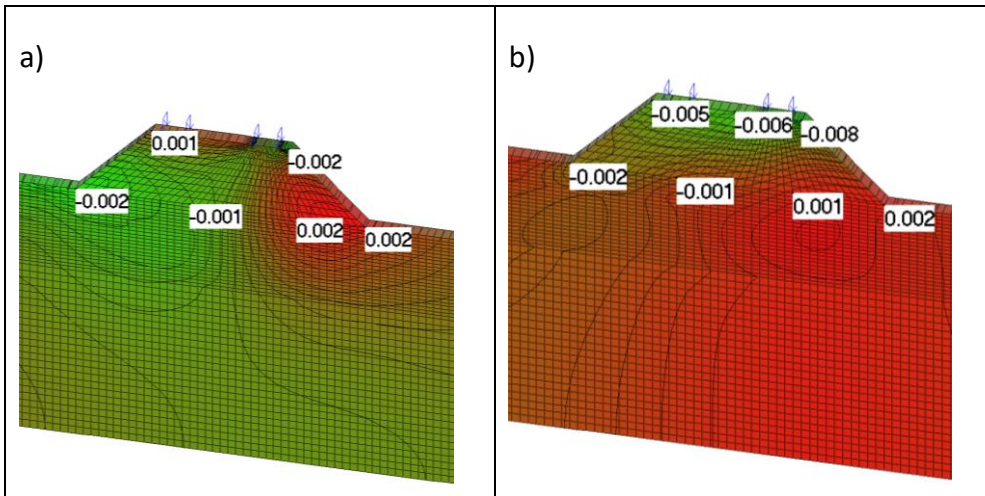
As a result of calculations of the standard design, the vertical deformations of the "mound-bottom" system are up to 29 mm, which significantly exceed the maximum permissible deformation values from the weight of the train load equal to 5 mm. These deformations will

continue to progress in the future, due to the degradation of the ever-frozen base of the newly constructed second path.

To reduce the deformability of the "mound-base" system in the construction of second tracks, the construction of a lightweight mound made of extruded polystyrene foam was used. In Fig. 4 shows the calculation scheme (a) and the results of calculating the vertical deformations of the elastoplastic solution (b).



**Fig. 4.** Calculation scheme for the construction of the embankment of the second tracks. 1 – soil embankment, 2 - expanded polystyrene, 3 - thawed soil, 4 - seasonally freezing soil, 5 - soils of second track precipitation; 6 - frozen soil



**Fig. 5.** Calculation scheme for constructing the embankment of the second tracks. Horizontal deformations in the level of paths and bases. A) using lightweight embankment technology, b) no activities

Fig. 5 shows the results of calculating the horizontal deformations by elastoplastic solution.

As a result of calculations the vertical deformations "mound-bottom" system are up to 13 mm, which reduces the deformability by half. With a sufficient compaction, these deformations will not increase in the future, since the material of the body of the second paths is a good heat insulator. Horizontal deformations decreased from 8 mm to 1 mm. Stacking of expanded polystyrene reduces labor and construction costs.

### 3 Conclusions

1. In this paper, we consider the development of road infrastructure with the construction of light embankments from blocks of extruded polystyrene in the construction of roads and other engineering structures on a weak and ever-frozen base.

2. The elastic-plastic model with the yield criterion was used to describe the work of variable stiffness design. This elastic-plastic model has been taken from existing material of engineering and geological surveys.

3. As a result of the study, the design using the technology of a light embankment showed a reduction in vertical deformations of more than 50%. The horizontal deformations are 1 mm and are within the permissible range.

4. The development of road infrastructure technology in this direction is necessary with the development of normative documents for the construction of second ways of permitting permafrost soils.

5. Using lightweight mounds allows you to reduce labor and construction costs.

### References

1. S.A. Kudryavtsev, U.B. Berestyanyy, T.U. Valtseva, et.al. *1st International conference on new developments in geoenvironmental and geotechnical engineering*. November 9-11, University of Incheon. Korea. 423-427 (2006)
2. S.A. Kudryavtsev, T.U. Valtseva, et.al. *9th International Conference on Permafrost (NICOP) and the field trip followed at the University of Alaska Fairbanks in Fairbanks, Alaska*. June 29-July 3, USA, 323-324 (2008)
3. S.A. Kudryavtsev, et.al. MATEC Web of Conferences, **106** (2016)
4. S.A. Kudryavtsev, A.V. Kazharsky, et.al. Embankment on permafrost Eastern polygon of Baikal-Amur Mainline. Int. Scientific Conf. on Transportation Geotechnics and Geoecology, Saint Petersburg, May 17-19, **189**, 774-782 (2017)
5. S.A. Kudryavtsev, Kazharsky A V et.al. *Procedia Engineering*, **165**, 1080–1086 (2016)
6. S.A. Kudryavtsev, et.al. MATEC Web of Conferences, **73**, 05002 (2016)
7. S.A. Kudryavtsev, et.al. MATEC Web of Conferences **73** 05007 (2016)
8. S.A. Kudryavtsev, *Soil Mechanics and Foundation Engineering*, **45**, 177-184 (2004)
9. A. Sirotkina, E. Fedorovich, V. Sergeev, *Psychology of Learning and Motivation - Advances in Research and Theory* **67**, 101–106 (2017), doi:10.1016/j.jppr.2017.01.007
10. V.G. Kiselev, V.V. Sergeev, E.N. Rouzich, *Corrosion Reviews* **35**, 47–51 (2017), doi:10.1515/corrrev-2016-0049