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Increasing the bearing capacity of the soil of the roadbed on weak foundations in Central Yakutia

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Abstract. The article discusses the issues of assessing the increase in the bearing capacity of the soil of the embankment subgrade in difficult conditions. The features of embankment operation in areas of permafrost distribution are considered. Special attention is paid to the issue of stability of embankments on weak foundations. Two options have been proposed to increase the bearing capacity of the subgrade soil: the use of a volumetric geoshell at different levels of the embankment. Recommendations are given to increase the bearing capacity of soil working in difficult soil and geological conditions.

1 Introduction

Depending on local conditions, the type of soil and the design of the subgrade, various deformations may develop in it. Practice shows that, despite certain costs for repairs and strengthening of the road surface, the condition of the road practically does not improve.

The calculation of road pavements is based on indicators of the mechanical characteristics of embankment soils when assessed according to two strength criteria [1, 2]: elastic deflection; the condition of shear resistance of the underlying soil and low-cohesion structural layers. The most important element in the calculation of road pavement according to the elastic deflection criterion is the determination of the overall design modulus of elasticity of the structure.

When designing a roadbed, in each specific case it is necessary to evaluate:

1. Stability of the slope parts of the embankment to collapse;
2. Possibility of constructing road pavement on a base of local soil.

Therefore, to solve these problems, it is necessary to determine the values of the design parameters of strength and deformation characteristics for specific construction conditions.

2 Problem definition

Loss of general stability of embankment slopes and excavations is one of the most common types of road subgrade deformations.

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Assessment of slope stability is usually solved within the framework of the Coulomb-Mohr strength condition, which considers the equilibrium conditions of a soil mass on a section of a structure one meter long, with vertical edges, without taking into account the forces acting on the lateral edges (plane problem).

In the field of calculating the stability of slopes of soil structures, there are many methods suitable for assessing the stability of slopes of embankments from local soils, among which, according to ODM 218.2.006-2010 [3]:

a) limit equilibrium method;
b) finite element method;
c) combined method;
d) spatial column method.

Under the influence of external forces and processes occurring in the roadbed and road pavement, various irregularities appear on the roadway - waves, ruts, potholes, subsidence, deflections, landslides. The appearance of irregularities negatively affects the efficiency of road transport, contributes to a decrease in road safety, reduces the durability of the road, and reduces the time between repairs.

The use of existing geosynthetic materials in road construction does not fully ensure constant reliable passage and operation of construction equipment during the construction and repair of roads, especially in the off-season. Most often, the problem of strengthening weak foundations is encountered in areas of the I road-climatic zone. Therefore, it was decided to use a volumetric geoshell on a weak foundation.

To perform these calculations, the stress-strain state of the soil at the base of the embankment is assessed (Table 1). This takes into account the stresses in the foundation that arise due to the load from the embankment's own weight (static loads) and from the rolling stock (dynamic loads).

Table 1. Physical and mechanical parameters of the geoshell.

Name of characteristic (indicator)	Indicator value
1. Geoshell dimensions:	
- geoshell length, m	2.4
- geoshell width, m	3.0
- geoshell height, m	0.3
- geoshell coverage area, m2	7.2
- geoshell volume, m3	2.16
2. Number of geocells:	
- in a shell along the length, pcs.	4.0
- in a shell in width, pcs.	7.0
- just in the shell	28.0
3. Dimensions of geocells:	
- length of the sides of geocells, cm	50 / 60 / 78 /100
- height of geocells, cm	0.3
- volume of geocells, m3	0.045 / 0.09
4. Shape of geocells	trapezoid
5. Number of attachment points for the geoshell to the frame, pcs.	22.0
6. Bottom outlets on three sides, cm	30 / 50 / 30
7. Surface density, g/m2	170.0 ±15%
8. Tensile strength, kN/m, not less	
- in the longitudinal direction	33.0
- in the transverse direction	30.0

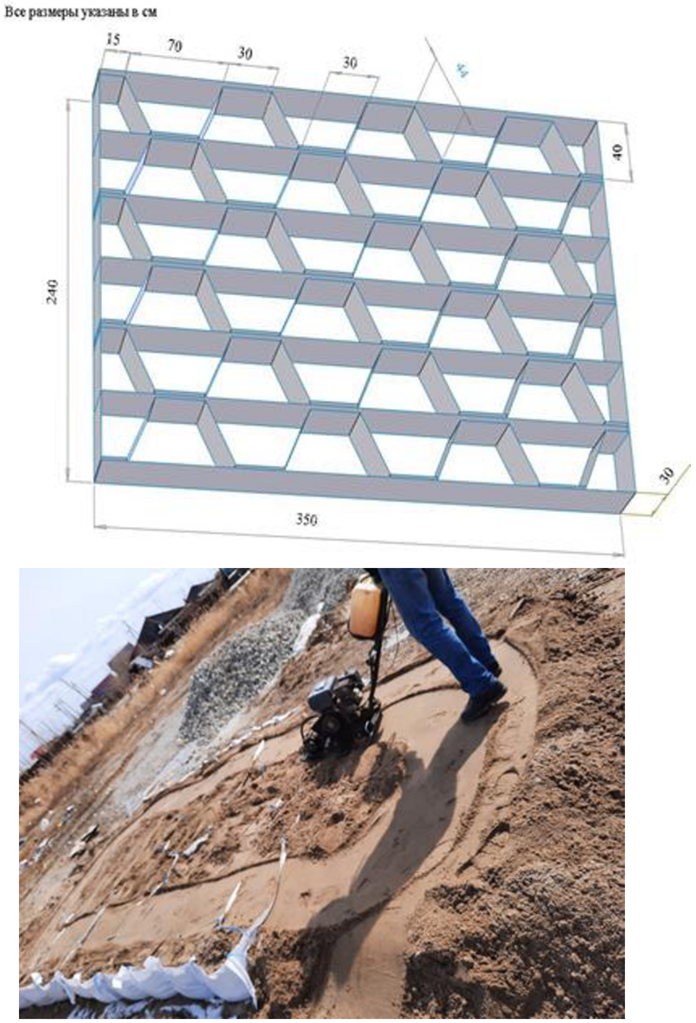

Fig. 1. Diagram and photograph of a multi-section geoshell in the process of compaction.

Backfilling of geoshell sections is carried out with an excavator or bucket loader. The multi-sectional geoshell is filled with fine sand (Figure 1). Construction sand is poured into sections using the “pull away” and “top” method. When filling sections with sand, it is necessary to ensure that the height of the soil layer above the technological frame is at least 10 cm. When using mechanical methods of backfilling (with an excavator), it is necessary to level the surface, manually add and level the soil until a uniform layer of soil is achieved above the geoshell.

After final compaction, soil samples were taken. Work was carried out to determine the elastic modulus using the HMP LFG dynamic loading installation [4].

Fig. 2. Determination of the elastic modulus by installing a dynamic loading HMP LFG.

According to the results of the study, the area where the multi-section geoenvelope was not used showed an elastic modulus value several times lower than the area with the geoenvelope (Figure 2).

Loss of general stability of embankment slopes and excavations is one of the most common types of road subgrade deformations. In Russia, the so-called method of moments is more often used in calculations. The essence of the method is to determine the stability coefficient, equal to the ratio of the shearing and holding moments relative to the center of the circular cylindrical sliding surface. Although, along with the method of moments, the method of force balance is also used, which comes down to determining the stability coefficient through the balance of the projections of forces arising in the embankment compartments. The stability coefficient for both methods is determined by the formulas:

Calculation of safety factor by the Morgenstern-Price method, moments:

$$Ku = \Sigma Mreact\ i / \Sigma Mact\ i \tag{1}$$

Calculation of safety factor by the Morgenstern-Price method, forces:

$$Ku = \Sigma Fx\ react\ i / \Sigma Fx\ act\ i \tag{2}$$

3 Description of the research

To solve the problems, theoretical studies and numerical modeling were carried out. To develop a methodology for assessing the increase in the bearing capacity of soil when using a volumetric geoshell, a study was carried out by numerical modeling of the stress-strain state process using the finite element method using GeoStab software packages.

An embankment with a slope angle α = 36°, a load P = 5 kN/m2 and soils whose characteristics are given in table was used as a calculation model. 1. All calculations were carried out using the numerical method in the GeoStab Demo 7 software package. The range of changes in the specific gravity of the embankment soil (medium-sized sand, plastic sandy loam) is γ = 16.5-20.0 kN/m3 with a step of 1 kN/m3.

Three series of calculations were performed (an embankment without a geoenvelope, a geoenvelope located at the base of the embankment; a geoenvelope located at +0.5 from the base of the embankment) to create slip lines and calculate the value of the design value of the safety factor for the embankment on them (h = 2.5 m, b=10 m, slopes 1:m=1:1.5).

The results of studies of the physical and mechanical characteristics of the soil are given in Table 2.

Table 2. Physical and mechanical characteristics of soil.

Name of soil according to GOST 25100	Optimal humidity, %	Maximum density,**г/см³**	Specific gravity of soil at natural humidity, **γ, кН/м³**	Specific soil adhesion at natural humidity, **с, кПа**	Angle of internal friction at natural humidity, **φ, град**	Specific gravity of soil at full water saturation, **γ_{sat}, кН/м³**
Fine sand	15	1,68	15,0	3,0	28,0	31,0

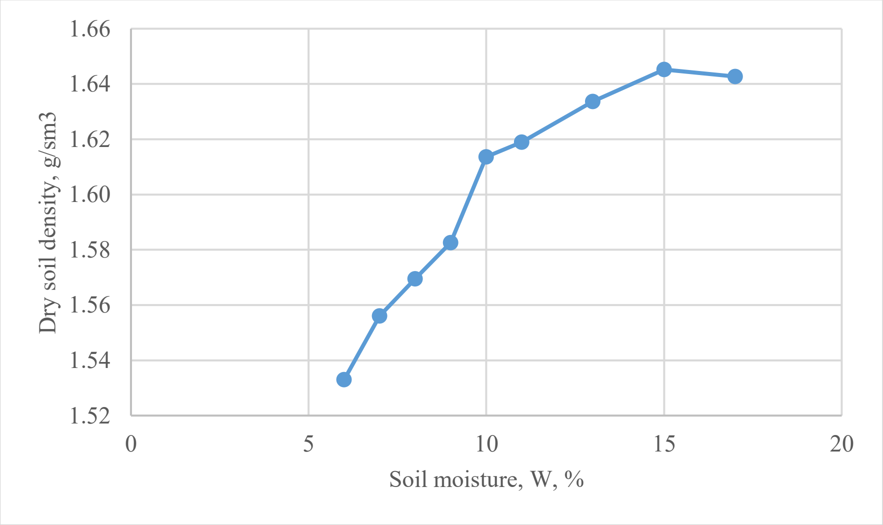

Fig. 3. Dry soil versus moisture graph.

Today, strength and deformation characteristics are determined depending on the calculated humidity [5]. It is known that the higher the soil moisture, the lower the elastic modulus, the lower the adhesion and the smaller the angle of internal friction (Figure 3). The elastic modulus can be increased by strengthening soils and reinforcing geosynthetic materials.

The studies were carried out at an experimental site. 3 options were considered: an embankment without a multi-sectional geoshell; with a multi-section geoshell on the base of the embankment; geoshell located +0.5 m from the base of the embankment.

1. Option 1. Embankment without a multi-sectional geoshell

The radius of the sliding surface is determined by the GeoStab program as critical and is R = 6.60 m. Based on current design standards, the permissible stability coefficient for embankment slopes is 0.993. The stability calculation is presented in Figure 4.

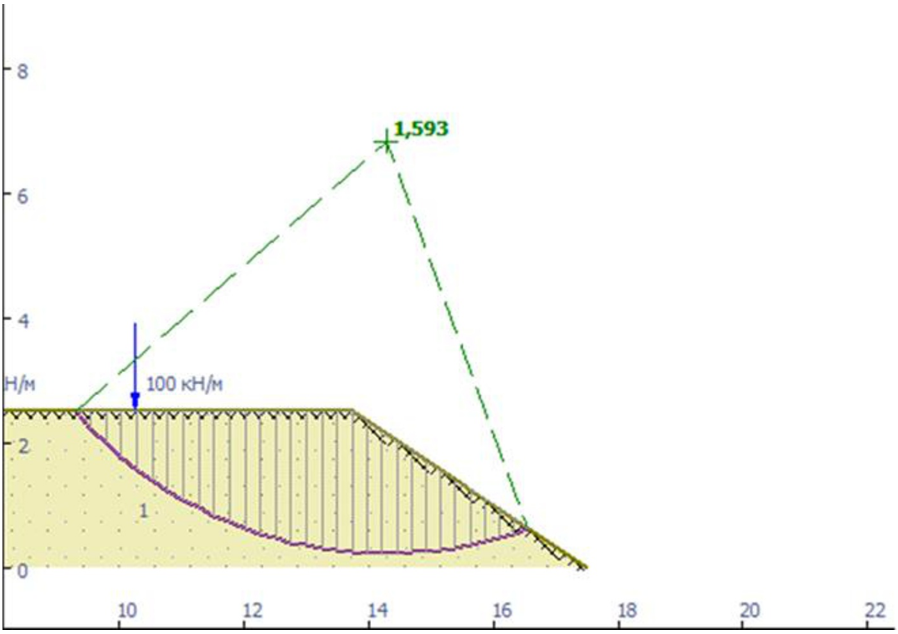

Fig. 4. Design diagram of the slope and results of stability calculations.

Calculation of the stability coefficient using the Morgenstern-Price method, points:

$$Ku = \Sigma Mreact\ i / \Sigma Mact\ i$$

$$Ku = 665{,}6 / 670{,}3 = 0{,}993$$

Calculation of the stability coefficient using the Morgenstern-Price method, forces:

$$Ku = \Sigma Fx\ react\ i / \Sigma Fx\ act\ i$$

$$Ku= 90{,}6 / 91{,}9 = 0{,}993$$

2. Option 2. Multi-sectional geoshell located at the base of the embankment

The radius of the sliding surface is R = 6.60 m. Based on current design standards, the permissible stability factor for embankment slopes is 1.665. The stability calculation is presented in Figure 5.

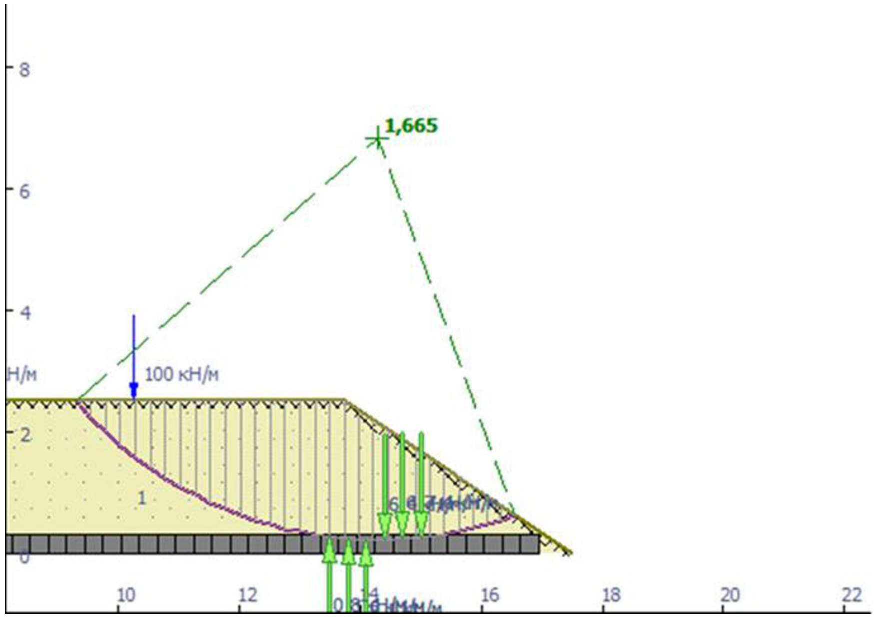

Fig. 5. Design diagram of the slope and results of stability calculations.

Calculation of the stability coefficient using the Morgenstern-Price method, points:

Ku = ΣMreact i / ΣMact i

Ku = 1115,9 / 670,3 = 1,665

Calculation of the stability coefficient using the Morgenstern-Price method, forces:

Ku = ΣFx react i / ΣFx act i

Ku = 151,0 / 90,7 = 1,665

3. Option 3. Multi-section geoshell located at +0.5 m from the base of the embankment

The radius of the sliding surface is R = 6.60 m. Based on current design standards, the permissible stability factor for embankment slopes is 1.613. The stability calculation is presented in Figure 6.

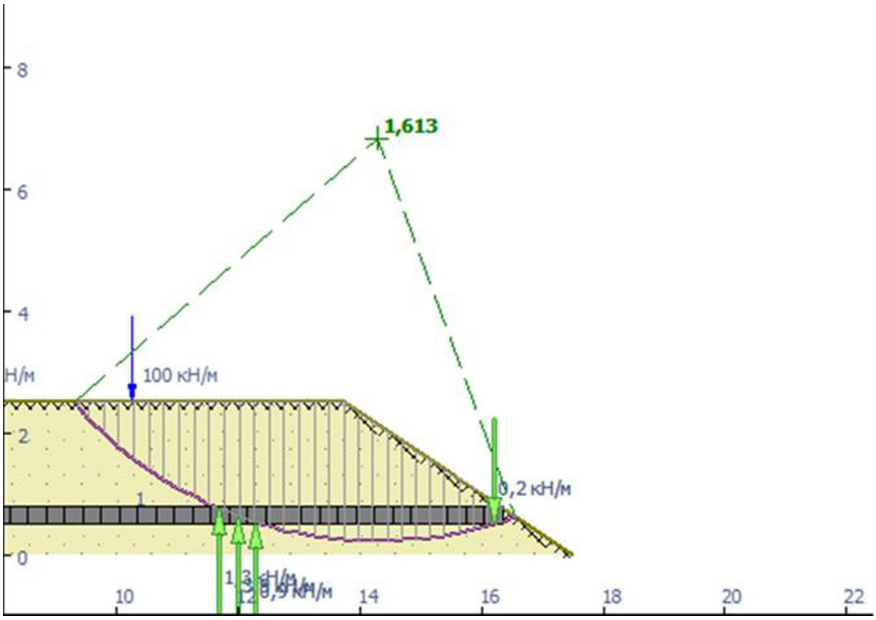

Fig. 6. Design diagram of the slope and results of stability calculations.

Calculation of the stability coefficient using the Morgenstern-Price method, points:

$$Ku = \Sigma M react\ i / \Sigma M act\ i$$

$$Ku = 1081,0 / 670,3 = 1,613$$

Calculation of the stability coefficient using the Morgenstern-Price method, forces:

$$Ku = \Sigma Fx\ react\ i / \Sigma Fx\ act\ i$$

$$Ku = 145,0 / 89,9 = 1,613$$

Based on the results of three calculations, the best result was shown by the geoshell located at the bottom of the embankment. The stability coefficient increased from 0.933 to 1.665, which meets the “ODM 218.2.078-2016 Guidelines for choosing a design for strengthening the slopes of the subgrade of public roads” [6-16], the stability of the slope meets the requirements. Consequently, the use of this technology is the most effective in relation to the value of the stability coefficient of the studied options No. 1 and 2.

The design and construction of highways and site facilities in permafrost conditions must be guided by the following principles for the use of foundation soils in a frozen or thawed state:

- ensuring the elevation of the upper permafrost horizon (UHLM) not lower than the base of the embankment and maintaining it at this level throughout the entire period of operation of the road (the estimated state of the base soil is frozen);
- allowance for thawing of the soil at the base of the embankment during the operation of the road, taking into account the permissible settlement of the pavement (the calculated state of the base soil is thawed).

The design principle is chosen based on the climatic and permafrost-soil conditions of a particular section of the route for the designation of structures and the guiding elevation of the edge of the roadbed, technology and timing of work. For sections of the route with similar permafrost and soil conditions, the same principle of using soils at the base of the roadbed should be followed. Provides for preliminary thawing of foundation soils and drainage of the road strip before the construction of the embankment. A necessary condition for ensuring this principle is the preservation of a positive average annual soil temperature at the base of the embankment due to the heat-insulating material. Soil embankments built in winter must have a height of at least 2.0 m, which will protect the seasonally thawed layer at the base of the embankment from spreading.

In areas with large (height more than 1.5 m and diameter more than 6 m) heaving mounds of the embankment, it is necessary to design according to the first principle, providing for the removal of the mounds to the depth of peat in the adjacent hollows, the subsequent filling of the resulting pit with peat to the entire depth with a margin of its settlement and the construction of a single soil slab using a multi-sectional geoshell with sections filled with mineral material.

4 Conclusions

- The study showed that the strength of the geoshell meets the requirements for them. The walls of the sections withstood the load.

- Requirements for soils filling geoshells must be regulated, depending on the conditions of use. Using local soils can significantly reduce construction costs.

- Mathematical modeling methods allow us to take into account many factors at the design stage and eliminate the most common ones that affect the stability of the embankment of the roadbed.

The use of a multi-section geoshell will allow:

- increase the service life (without major repairs) due to reliable protection of the subgrade from water and wind erosion;
- ensure reliable and safe operation of facilities built in flooded areas;
- in the future, during repairs and maintenance, to achieve savings in capital investments during construction and major repairs of facilities, by reducing the height of embankments and reducing the volume of materials used, using a wide range of materials (it is possible to use not only sand as a material for filling sections, crushed stone, but also various mixtures of soils, including local soil);
- will ensure reliable and safe functioning of the base of the roadbed of roads built on weak unstable soils.

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