Improvement of structures and methods for construction of unpaved roads in conditions of West Siberia

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Abstract. The article discusses the roads construction methods in Western Siberia, built in difficult engineering and geological conditions. Consideration includes both traditional methods of constructing roads on a weak base and modern methods, including using geosynthetic materials. A bio-positive construction, the use of which is aimed at preserving and protecting the environment has been proposed. The main differences of the proposed design from the existing ones are given. A design diagram and a mathematical model for determining the overall stability of a bio-positive structure in complex geotechnical and hydrological conditions are given. The full-scale experiment results are given.

Introduction

The Western Siberia geotechnical conditions, characterized by the occurrence of weak, water-saturated soils and peats, as well as the large extent of the territory, determined the most common road construction and technology.

The method of refining is based on the complete or partial cleaning of the base from weak soils: peat, organic sapropel, organic sapropel and their replacement with durable low-compressible soils. Refining is carried out to the mineral bottom, followed by its replacement with construction soils (sand of various sizes). The peat removal from the embankment base in swamps of types I, II and III-A is carried out by excavators, on swamps of type III-B by the method of extrusion by embankment weight. In swamps of type I (up to 1 m deep), peat can be removed by swamp modification by bulldozers [11].

The method can be implemented both in summer and in winter periods. In the warm period of the year, excavation is carried out on an I, II type swamp (at a depth of 4 m) with the obligatory use of inventory boards or a floor plank to ensure the sustainability of equipment, therefore it is most widely used for work in the winter. When carrying out the refining, all the peat is stored either on the road sides, or on the sites allocated near the road. It is necessary to reclaim all the peat extracted, for which it is collected and transported to special storage sites after refining.

Freezing
In the autumn-winter period, the swamp massif is frozen so is the peat plate; in the pre-spring period - piling earth road from mineral soils and arranging heat-insulating prisms from peat.

The method of soil freezing is limited to the period of work only in the autumn-winter period as well as the average annual temperature of the construction area is not higher than –10 °C and is applicable only in wetlands of type I. This condition severely limits the applicability of this technology.

Device of a plank flooring. In this case, in order to strengthen the base of the embankment, bog beds (pre-prepared wood, cut from knots with a given diameter and a certain length) are placed on the marshy areas. First, the longitudinal Autun is laid down, forming a frame, the main Autun flooring is laid on them with a solid carpet “to the side”. Works are performed by hooks equal in length to the pitch of the longitudinal slits.

After laying, the plank flooring is fastened with wire twists or metal straps.

The use of geosynthetic materials as reinforcing allows to provide the bearing capacity of the structure, due to the possibility of reinforcing elements to perceive the tensile forces arising in the soil mass [1].

Analysis of recent achievements and publications
Works of V.D. Kazarnovsky, Ye.V. Shcherbina, V.M. Yumashev, L.S. Timofeyeva, A.V. Kochetkova, A.G. Polunovsky, A.A. Novikov, Yu.R. Perkov, A.P. Fomin, Yu.M. Lvovich, G.S. Pereselenkov, L.M. Biryukova, Yu.A. Aliver, N.V. Tabakov, B.A. Vinogradov et al are dedicated to research in this area [2,3,4].

Such organizations as Soyuzdorproekt, OJSC, SOUZDORNI, OJSC, FGUP ROSDORNI, GIPRODORNI, OJSC, TSNII, OJSC, NIIOSP, OJSC, FSBEI HPE MADGTU, FSBEI HPE MGSU are closely engaged in study of geosynthetic materials. Field and experimental research was carried out as early as before the 90's in the USSR, and a part of results on them, mostly nonwoven geotextiles, were incorporated into sections of the regulatory documents.

Research works on development of reinforced earth structures were conducted at MGSU at the site of NP and UTs ECOGEOS[5].

Formulation of goals and organization of work tasks.
Analysis of foreign literature sources and library materials showed that geofabrics are most optimal for development of a bio-positive structure of a road, as they have solid structure at high strength parameters and fulfill several functions at once: reinforcement, separation of layers and filtering [6,7].

Several cases of diagrams and parameters of bio-positive structure were reviewed.

![Figure 1. Embankment using non-woven geotextiles.](image)

This structure can be used for an insignificant period, as nonwoven geotextile does not have sufficient firmness and susceptible to considerable deformations to about 120%. Using of the structure with reinforcing layers of nonwoven geotextile is possible as technological temporary driveways.
Figure 2. Diagram of embankment using 3D geocells.
Embarkment with layers of 3D geocells. Apart from the 3D geocells themselves, nonwoven geotextile must be used in the structure as a separating and filtering element. Geocells should be filled with crushed stone, body of the embankment is filled with medium sized sand of medium density.

Figure 3. Embankment scheme using flat geogrids (geogrids).
A separating layer of nonwoven geotextile is needed for embankment with reinforcing elements of flat geo-meshes or geogrids, as well as with 3D geocells. For effective work, 30 cm crushed stone backfilling is recommended.

Figure 4. Diagram of embankment using geofabric.

Table 1. Various cases of diagrams and parameters of bio-positive structure

| Item No. | Structural diagram | Parameters of structure materials | Note |
|----------|--------------------|-----------------------------------|------|
| 1.       | Structure of nonwoven geotextile laid in one or several | Nonwoven geotextile, density is not less than 500 g/m². Embankment is sand of medium size, medium density. | The structure has an insignificant service life, applicable only for installation of technological driveways. |
2. Structure of 3D geocells

Nonwoven geotextile, density is not less than 500 g/m², laid onto the base. Geocells filled with crushed stone. Embankment is sand of medium size, medium density. Considerable time input for preparation of the base; use of two types of geosynthetic materials. Use of two types of soils for earthwork.

3. Structure of geofabric

Geofabric; Embankment is sand of medium size, medium density. Laying of geosynthetic materials immediately onto the surface of the base (swamp) cleared from bushes and scrubs.

4. Structure of geo-meshes (geogrids)

Nonwoven geotextile, geo-mesh (geogrid). Embankment is sand of medium size, medium density. Considerable time input for preparation of the base; use of two types of geosynthetic materials. For more effective service, backfilling with crushed stone is recommended (30 cm), which will ensure better cohesion with the soil of the embankment, and then with the sand.

Basic research material

Based on these considerations, it seems to be most reasonable to use the diagram with a single layer or multiple layer highly reliable laying in the earthwork structure. In this case, one or more layers of reinforcing materials must be placed on at the bottom of the earthwork to increase the load-bearing capacity of the base and ensure total stability of the structure. In order to ensure time between overhauls and assure quality of the road topping (for example, to exclude rutting), the reinforcing layer shall be located at the top of the earthwork under the layer of crushed stone. Height of the earthwork is defined by the design and depends on the design vertical profile of the road.

The principle diagram of the bio-positive structure of road is presented in Figure 5. On the basis of the analysis of the reinforcing materials, high endurance geofabric was chosen as a reinforcing material because it can be laid immediately onto the surface of the base soils, additional use of nonwoven geotextiles is necessary to use geo-meshes and geogrids.

Such structure allows refusing from replacement of the base soils, installation of enclosing structures, placement of groundsill flooring and other special activities. A positive property of the structure is absence of limitations on performance of works depending on annual seasons.

![Figure 5. Principle diagram of bio-positive structure of road](image)
It should be noted that the design of bio-positive structure is based on the principle of ensuring its strength and stability on soft soils of the base, "floating structure". In this case, settlement of the bio-positive structure base can reach high values in meters and continue for a long time. This is the essential difference of the bio-positive structure from the existing structures of earth roads.

The main difference of the proposed bio-positive structure from the previously known solutions is:

1) The bio-positive structure and the technology are applicable for construction in complex hydrogeological conditions characterized by occurrence of a large mass of soft water saturated, structurally unstable soils and peats (general stress-strain modulus is less than 5 MPa) with groundwater discharge (basically, swamps).

2) Settlement of the base of the proposed bio-positive structure of road reaches more than two meters, while the earth structure is commissioned right from the time of construction.

3) Operation period of the structure without performance of overhaul is more than 30 years.

4) Impact on the environment caused by construction using the bio-positive structure is mitigated compared to the previously known solutions (volume of technogenic soils decreased more than 2.5 times; the natural hydrogeological mode is not disturbed).

Calculation of bio-positive structure is conducted per the 1st limit state (base stability) by the flat sliding surface method. As a result of the calculation, we find tensile force of the geofabric necessary for provision of stability of structures.

Loss of stability of the earthwork is possible on two kinematic diagrams: shear of soils on top of the reinforcement; shear of the base soils at the bottom of the reinforcement (foundation uplift) (Figure 6).

\[
T_{ad} = \frac{1}{2} \times \lambda_a \times \gamma \times h^2
\]
where: $\gamma$ – is a specific weight of embankment soil, $h$ – height of embankment, $\lambda_a$ – is a coefficient of active soil pressure equal to:

$$\lambda_a = t g^2 \left(45 - \frac{\psi_{ns}}{2}\right)$$

(4)

Resistance to shear without account of adhesion will be equal to:

$$Q_{ns} = \frac{1}{2} \times \gamma \times n \times h^2 \times t g \psi_{ns}$$

(5)

where: $n$ – is the slope steepness, $t g \psi_{ns}$ – is a design value of coefficient of friction between the embankment soil and the reinforcement element.

Resistance to the shear at bottom of the reinforcement on condition that the embankment soils are completely water saturated can be determined for the initial and the final phases of the base soil consolidation process. For the initial stage of construction, resistance to shear is defined only by the force of the base soil cohesion and can be calculated:

$$Q_{os} = c_o \times n \times h,$$

(6)

where, $c_o$ – is a design value of specific cohesion of the base soils and the reinforcement defined for the full consolidation conditions.

For the final phase of construction and commissioning, at completed consolidation of the base soils:

$$Q_{os} = a_o \times n \times h + \frac{1}{2} \times \gamma \times n \times h^2 \times t g \psi_{os},$$

(7)

where, $a_o$ – adhesion of the base soil and the reinforcement interface, $t g \psi_{os}$ – is a design value of the coefficient of friction between the base soil and the reinforcement defined for the conditions of full consolidation.

At the set value of the assurance coefficient, the tensile force in the reinforcing material can be found from the condition (2):

$$R \geq T_{ad} - Q_{os}$$

(8)

With the value of the requisite tensile force available, depending on the type of the geosynthetic material, we can find its necessary lasting durability and the grade.

Summary

The data of the physical and mechanical characteristics of the base and earth fields are required, as well as the values of contact strength between the geofabric and the ground, which can be determined experimentally or using reduction factors for the calculation and design of a bio-positive design.

The selected and experimentally tested scheme of the bio-positive construction of unpaved roads using high-strength geosynthetic materials was introduced in the conditions of Western Siberia at the Salym oil fields [8,9,10].

Analysis of field observations allowed to establish:

• Throughout the site in the bio-positive structure no local destruction of the roadbed and the pavement of the unpaved road was revealed;
• Values of actual sediment turned out to be slightly less than calculated. In this case no direct dependence of precipitation on the thickness of the weak layer was recorded.
• The unpaved road is in a steady state throughout the entire monitored area, with no need for repair work.

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