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Use of geosynthetics for stabilization of road embankment slopes in complicated ground conditions

Uso de geosintéticos para la estabilización de pendientes de terrenos en condiciones de terreno complicadas

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ABSTRACT: The slope stability of high road embankments is a relevant challenge for sites with soft soils in Eastern Europe. Landslides and road embankment settlements can lead to the deterioration of transport and operational conditions, an increase in the structure's maintenance cost, or the failure of a transport structure. However, the use of geosynthetics allows for slope stability. The M-11/P2 highway project includes a road embankment up to 15 m high and an overpass. The highway is located in the western part of Belarus and passes through an area with complicated ground conditions. Peat, sapropel, silty and fine sands lie in the base of the roadbed. Comparative calculations of the embankment with and without geosynthetics for reinforcement included assessments of the embankment slope stability, subgrade settlements and cost. The comparison showed the necessity of the slope reinforcement. Therefore, multilayer slope reinforcement with high-strength woven geotextiles was applied. Also, the replacement of peat soil and the installation of a reinforced layer were provided at the base of the embankment. Moreover, the final project with reinforcement measures is more cost-efficient than the option without reinforcement. The case history described is one of the first projects in Belarus.

KEYWORDS: road embankment, slope stability, factor of stability, soil reinforcement, geosynthetics.

1 INTRODUCTION

The terrain of Belarus is mainly formed by glaciations. Buildings and structures usually interact with the soils of the near-surface part of the Quaternary deposits. 88% of them are of the glacial complex (Busel 2020). A feature of the territory is a relatively high water cut (Belarus in Maps 2017, Kolpashnikov 2004, Lukashev 1969).

The M-11/P2 bypass road around the city of Lida in the western part of Belarus (Figure 1, 2) is currently under reconstruction. The construction site is located in complicated geological conditions. The project provides for the construction of an overpass over the railway tracks and a secondary road (Figure 2). The maximum height of the embankment at the approaches to the overpass is 15 m.

According to the current design standards of Belarus for highways (TKP 200-2018), embankment slopes with a height of more than 12 m must be checked for overall stability. This is the procedure that was executed during the design process.

Until recently, the use of high-strength geosynthetic materials for reinforcement of subgrade soils was not widespread in Belarus. While it is commonly used worldwide (Vaníček et al. 2019, Klompmaker et al. 2019, Mahajan et al. 2022). However, the construction project discussed in the paper is one of the first known projects to have been implemented in Belarus.

Figure 1. Location of the construction site on the map of Belarus.

Figure 2. Location of the overpass with approaches to it.

2 GEOLOGICAL CONDITIONS

The construction site faces difficult geological conditions. Poor conditions for surface drainage due to the flat terrain and high groundwater level led to waterlogging in the area. The geological structure in the area that approaches the overpass is as follows: at the surface, there is a layer of soft soil (peat and sapropel) up to 1.5 m thick, followed by a layer of moraine sandy loam up to 2.9 m thick, below which is silty sand up to 3.8 m thick, and finally, a layer of medium sand. The groundwater level is 0.2…0.3 m below the ground surface. A fragment of the longitudinal profile of the embankment on approaches with geological structure is presented in Figure 3. The characteristics of the base soils are listed in Table 1.

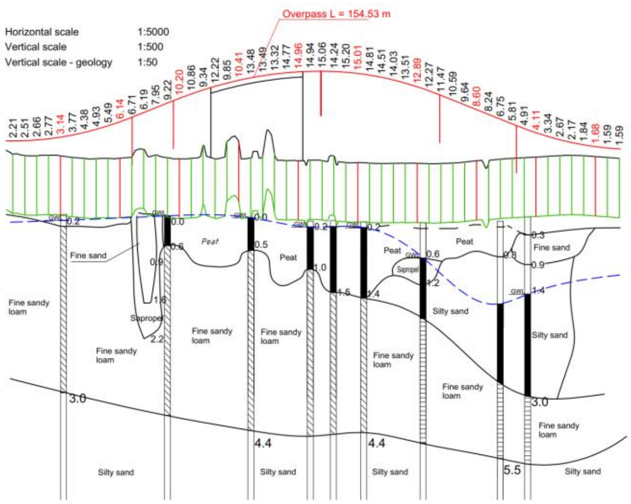

Figure 3. Road profile fragment.

Table 1. Design properties of soils. Unit weight γ_{unsat} (kN/m^3), unit weight saturated γ_{sat} (kN/m^3), effective friction angle φ (°) and effective cohesion *c* (kPa).

Soil	γ_{unsat} (kN/m^3)	γ_{sat} (kN/m^3)	φ (°)	*c* (kPa)
Fine sandy loam	21.2	21.2	26.0	9.0
Silty sand	17.5	19.3	34.0	9.0
Medium sand	17.3	23.0	29.0	3.0

3 PROJECT DESIGN ASPECTS

3.1 *Basic approach*

Before the appearance of high-strength geosynthetic materials on the market, normative documents allowed the use of non-woven needle-punched geotextiles according to (STB 1104-98) as reinforcing layers in the embankment. The method of calculation of slope stability with reinforcing layers was presented in the Manual (P2-01 to SNiP 2.05-85). The calculations took into account the tensile strength, the thickness of the interlayer and the raw material of which it is made. The use of non-woven needle-punched geotextiles for soil reinforcement has not been developed due to their low tensile strength and high elongation values.

The conventional approach to solving the problem of ensuring the stability of the slopes of high embankments in Belarus involves altering their design, specifically by reducing the steepness of the slopes and/or installing berms. This method has the disadvantage that it increases the area of land occupied by construction and the volume of excavation work.

An integrated approach to the problem of the stability of road subgrades in Belarus and methods for calculating the stability of slopes was proposed by professors I.I. Leonovich and N.P. Vyrko. This was reflected in scientific materials (Leonovich, Vyrko & Bogdanovich 2006) and later formed the basis for a regulatory document for design, known as the technical code of established practice TKP 200-2018 “Automobile roads. Road subgrade. Design specification” (TKP 200-2018).

3.2 *Initial slope stability analysis*

According to the regulatory document (TKP 200-2018), the circular cylindrical sliding surface method is used to calculate the stability of embankment slopes. In this particular instance, it is recommended that the minimum acceptable value for the stability safety factor *FS* is 1.30.

Two cross-sections were identified to the right and left of the overpass to calculate the stability of the embankment slopes. The selection of the design section was carried out according to the criteria of the height of the embankment and the geological structure of the base. The presence of a layer of peat and sapropel at the base of the embankment was not taken into consideration since it was planned to completely remove it and replace it with the soil of the embankment. The article examines cross-section No. 3 as one of the most unfavorable conditions. Figure 4 presents the selected design cross-section.

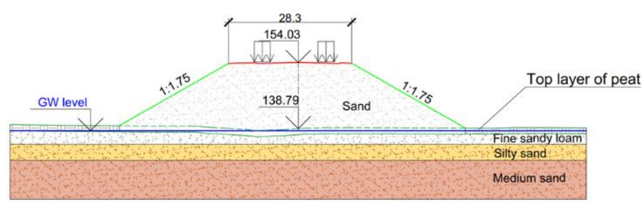

Figure 4. Design cross-section No. 3.

The project intends to fill the embankment with soil from a nearby quarry. That is fine sand with design strength properties such as effective cohesion c = 1.3 kPa and effective friction angle φ = 29.1°. The design temporary loading parameters were adopted in accordance with (GOST 3260-2014).

The geotechnical software GEO 5, module “Slope Stability”, was used to automate the calculation. The software facilitates the assessment of the slope stability by utilizing diverse techniques, including the round-cylindrical sliding surface method, also known as Fellenius method. The result of the calculation of the embankment slope on the left for the chosen cross-section is presented in Figure 5.

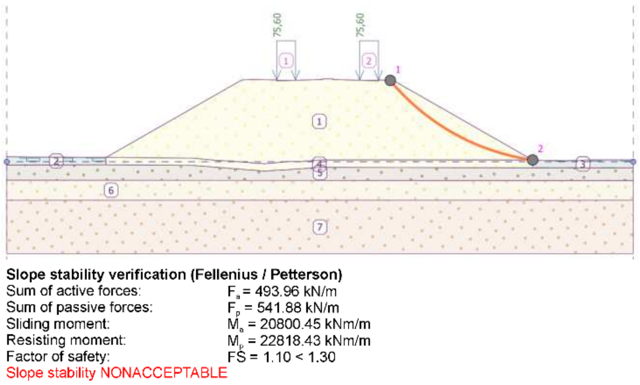

Figure 5. Result of slope stability analysis.

The calculated safety factor was $FS = 1.10$, which is below the standard requirement. Based on the analysis of the remaining cross-sections, an area of the embankment with a length of 35 m was determined, where the stability of the slopes is not guaranteed.

3.3 *Slope stabilization measures*

An enhancement in the overall stability can be achieved either by improving the stressed state of the soil mass or by increasing the shear characteristics of soils. In accordance with (TKP 200-2018), measures to improve the stability of the roadbed include:

- slope positioning;
- arrangement of unloading berms;
- arrangement of counter-banquets;
- use of reinforcing layers;
- reducing the height of the slope;
- use of lightweight materials in the slope;
- use of soils with increased values of φ and *c* in the embankment.

The option of using reinforcing layers made of geosynthetic materials was chosen as a measure to enhance the overall stability of the slopes, taking into account all the conditions of the project and based on a technical and economic comparison of the available alternatives.

As an alternative, it was considered to change the design of the embankment by lowering the slopes and installing berms. This option turned out to be economically unfeasible due to an increase in the volume of excavation work and compensation to land users for additional land allocation. The use of other soil to fill the embankment was also not economically feasible. This would lead to an increase in the cost of the facility due to a significant increase in transportation costs for soil delivery.

Reinforcing the embankment soil with geosynthetics allows for preserving the geometric contours of the embankment. Accordingly, the volume of excavation work and area of land allotted for the construction remain unchanged. The technology for implementing reinforcement layers is simple and relatively inexpensive. Geosynthetic reinforcement of a certain length is laid in multiple layers along the height of the embankment when the embankment is erected.

3.4 *Slope reinforcement and final slope stability analysis*

The determination of the quantity and length of layers, reinforcement spacing, and strength of geosynthetic reinforcement was made through calculations during the design stage.
The reinforcement layers are assumed to provide a holding force at the point of intersection between each layer and the potential shear surface under consideration. The calculation scheme is presented in Figure 6.

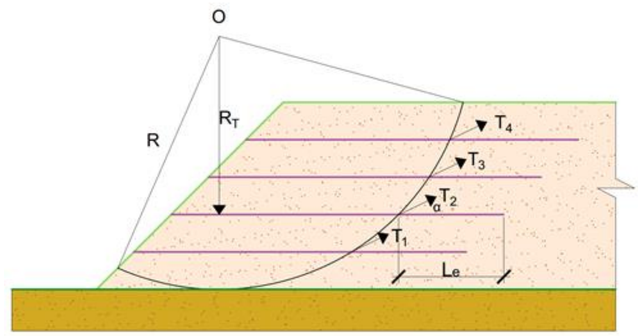

Figure 6. Design model for determining slope stability with reinforcement.

The safety factor *FS* is determined by adding a term that takes into account the tensile strength of reinforcement T_{allow} (see Eq. 1) (International Geosynthetics Society 2021).

$$FS = \left(\frac{M_R}{M_D}\right)_{\text{unreinforced}} + \frac{\sum T_{\text{allow}} R_T \cos\alpha}{M_D} \quad (1)$$

Where M_R and M_D are the resisting and driving moments for the unreinforced slope, respectively; R_T is the distance between the circular center and the located geotextile layer; T_{allow} is the allowable tensile strength of the reinforcement; and α is the angle of tensile force in the reinforcement with respect to the horizontal.

As the most affordable material, high-strength woven geotextiles were used as geosynthetic reinforcement at this facility. Each slope along the height of the embankment was reinforced with 6 layers of geosynthetic material 12 m long, as well as one lower layer of reinforcement at the base of the subgrade. Geotextiles have a long-term design tensile strength of at least 60 kN/m. The vertical reinforcement pitch is 2.0 m. An additional function of the lower layer of geosynthetics, which is positioned across the entire width of the base of the subgrade, is to facilitate uniform settlement of the embankment.

The conversion of the long-term design tensile strength of the material into the nominal tensile strength is carried out by applying reducing factors and a safety factor following the methodology (ISO/TR 20432 2007).

The appearance of the geomaterial is shown in Figure 7. The main design, physical, mechanical, and hydraulic parameters for the reinforcing geomaterial are given in Table 2. The result of calculating the stability of the embankment slope on the left for the design cross-section No. 3, taking into account reinforcement, is depicted in Figure 8.

Figure 7. High-strength woven geotextile Stabbudtex 150/50.

Table 2. Parameters of geosynthetic reinforcement. High-strength woven geotextile (Technical Data Sheet 2022).

Parameter	Unit	Value
Long-term design tensile strength in machine direction	kN/m	60 (-0)
Interaction coefficient (sand)	-	0.7
Tensile strength:		
- Machine direction	kN/m	150 (-0)
- Cross machine direction	kN/m	50 (-0)
Strain at nominal load:		
- Machine direction	%	10 (+1)
- Cross machine direction	%	10 (+1)
Dynamic perforation resistance	mm	16 (+0)
Resistance to static puncture	kN	9.5 (-0)
Characteristic opening size O_{90}	μm	90 (+/-30)
Water permeability	$l/(m^2s)$	7 (-3)
Width	cm	up to 540
Surface density	g/m^2	≈ 300
Raw material composition	-	100% polyester

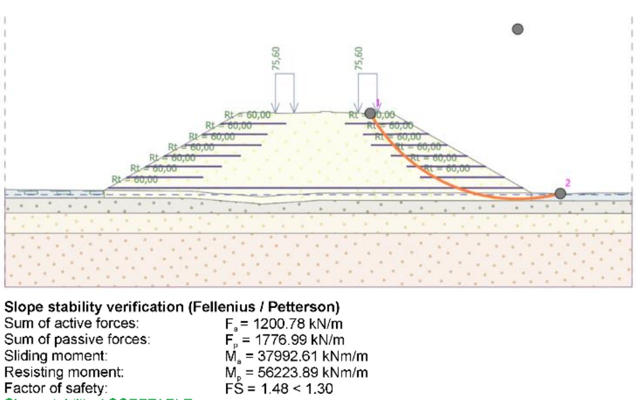

Figure 8. Result of reinforced slope stability analysis.

The calculated safety factor was determined to be *FS* = 1.48 > 1.30. Thus, the stability of the embankment slope is ensured in accordance with (TKP 200-2018).

To prevent water and wind erosion of slopes, the project provides for the laying of a special biodegradable fabric containing seeds of perennial grasses over a layer of plant soil with an average thickness of 10 cm. A fragment of a detailed drawing of reinforced embankment slopes is shown in Figure 9.

4 CONSTRUCTION ASPECTS

Construction work on the road was initiated in October 2022. The main stage of construction of the overpass and its approach embankments took place from March to December 2023. Work on anti-erosion protection of slopes is planned to be carried out after the winter period of 2023/2024.

Before placing the reinforcement material, the soil base was backfilled to the design marks, leveled, and compacted. The soil compaction coefficient was 0.98 or higher. During layer-by-layer filling of the embankment soil, reinforcement layers of high-strength geotextiles were laid according to the design solution indicated in Figure 9.

Pre-cut geotextile sheets were laid perpendicular to the axis of the embankment and secured with metal anchors to prevent displacement during the process of filling the subsequent layer of soil. A portion of the canvas was left on the outer edges to wrap the soil into a half-clip, the so-called reverse anchor.

Subsequently, a soil layer of 25 cm thick was poured on top of the laid canvas surfaces using a "pull" technique. At the same time, care was taken to ensure that construction equipment was not driven onto canvases that were not covered with soil in order to avoid damaging them. The soil layer was leveled and compacted with road rollers. After monitoring the degree of compaction, technological operations were repeated until the design parameters of the embankment were achieved. Figures 10 and 11 show a view of the filled embankment as it approaches the overpass. Work on the bridge deck is ongoing at the time of this writing.

5 CONCLUSIONS

One of the first projects in Belarus using high-strength geosynthetic materials to reinforce road embankment soils is described. The site is located in Lida, the western part of Belarus, in complicated geological conditions. The project includes the construction of an embankment and an overpass over the railway tracks and road. The road embankment leads to a 15 m high overpass. The road embankment stability was successfully ensured by the application of geosynthetic materials, such as the high-strength woven geotextile Stabbudtex 150/50.

Modern reinforcing geosynthetic materials possess high tensile strength. They enable the stability of massive slopes with significant steepness, including construction in challenging engineering and geological conditions, when used correctly. Furthermore, reinforcement technology itself is quite simple and economical. It does not require special mechanisms and reduces the volume of excavation work, thereby reducing the impact on the environment.

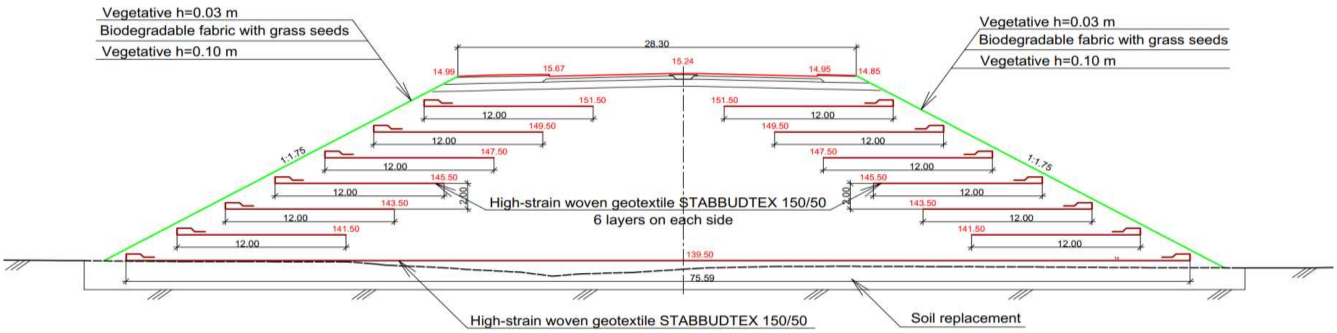

Figure 9. Cross-section of final reinforced embankment.

Figure 10. Reinforced embankment complete and overpass under construction.

Figure 11. Constructed embankment.

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