A R C H I T E C T U R E C I V I L E N G I N E E R I N G E N V I R O N M E N T
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SLOPE FAILURE CAUSED BY AN INCORRECTLY SELECTED REINFORCEMENT

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A b s t r a c t
The application of geosynthetics in hydrotechnical engineering requires an appropriate selection with respect to soil properties and operational conditions of the structures.
The paper presents the case of the slope failure of a deep drainage channel caused by the geotextile clogging phenomenon resulting from selecting an inappropriate material with respect to soil parameters.
Due to rapid changes of water level in the channel, which will occur during operation, it was required to protect the slope from periodically occurring seepage forces. The slope reinforcement was performed by placing the draining gravel layer between geotextile on the cohesive soil. On the top the openwork concrete plates were laid.
Despite the reinforcement, during intense rainfall even before the channel was filled, a long section of the slope slid down and destroyed the ecological reinforcement of channel bottom.
In the paper this phenomenon was explained by the analysis of slope equilibrium conditions, along with the laboratory tests of water permeability and the clogging process of the applied geotextile.

S t r e s z c z e n i e
Zastosowanie geosyntetyków w budownictwie wodnym wymaga odpowiedniego ich doboru w stosunku do cech gruntów i warunków eksploatacyjnych budowli.
W pracy przedstawiono przypadek osuwiska skarpy głębokiego kanału odwadniającego spowodowany zakolmatowaniem geowłókniny na skutek złego jej doboru w odniesieniu do parametrów gruntów.
Gwałtowne zmiany stanów napełnienia kanału, jakie będą występować w czasie eksploatacji, wymagały ubezpieczenia dolnej strefy skarpy przed powstającym okresowo nadciśnieniem spływowym. W tym celu wykonano umocnienie poprzez ułożenie na gruncie spoistym warstwy żwiru osłoniętej od góry i od strony dna kanału geowłókniną. Na niej ułożono ażurowe betonowe płyty, których otwory miały odprowadzać spływającą po napełnieniu wodę.
Pomimo wykonanego umocnienia, w czasie intensywnego opadu deszczu, jeszcze przed napełnieniem kanału, skarpa na dużej długości zsunęła się niszcząc ekologiczne umocnienia dna kanału.
Zaistniałe zjawisko zostało wyjaśnione poprzez analizę warunków równowagi skarpy oraz laboratoryjne badania wodoprzepuszczalności i procesu kolmatacji zastosowanej geowłókniny.

K e y w o r d s: **Geotextile clogging; Geotextile-reinforcement; Slope stability.**

1. INTRODUCTION

One of the fundamental issues related to earth structures are the problems connected with the stability of excavation slopes, as excavations interfere with the original state of stresses equilibrium in the soil. This is caused by the removal of load resulting from evacuating certain masses of soil and reduction of lateral stress σ_3. In design practice, the required tests of soil parameters and stability analyses are usually neglected, and design is typically based on the assumed inclinations of slopes of 1:1.5. Additionally in the conditions of water saturation of soil the forces interfering with stability may be supported by the influence of seepage forces. In the case of operation of water channels, when the water surface level is often lowered soon after the channel is filled and the soil saturated with water, this factor is particularly important [5, 7]. The most common means used to counteract the destructive results of seepage forces are costly filtration layers placed on the slope, although unfortunately they are often not tested thoroughly either. Such case is illustrated by the slope failure discussed in this paper which occurred even before the operation of the channel commenced. The aim of this study is a detailed analysis of the destruction causes.

2. DESCRIPTION OF THE ANALYSED STRUCTURE

The situation took place on a section of a drainage channel along the left bank of the Odra River. The channel was constructed pursuant to environmental requirements, in order to enable the aquatic fauna to migrate from the upstream to the downstream of the barrage (currently under construction). In the conditions of operation it will be necessary to periodically fill the channel in an artificial way. Raising the water level will result in saturation of the soil in the slope with water. After a rapid lowering of the water level, the soil will be prone to suffosion processes [2].

Analysed slope was reinforced by geotextile, geogrid and openwork concrete plates (Fig. 1).

After the designed reinforcements had been constructed, even before the commencement of operation, a superficial failure of the lower part of the slope occurred on a section of the channel. It was caused by rainfall waters that had flowed down from areas located above the channel edge and penetrated into the constructed reinforcements. This resulted in the damages shown in Figure 2.

3. EXPERIMENTAL INVESTIGATION

3.1. Stability analyses of a non-reinforced slope in natural soil conditions

In order to determine the geotechnical parameters of soils in the slope, field and laboratory tests pursuant to the reference standard [8] were conducted. Research has shown that the 3 m deep channel was constructed in the sediments of the Odra valley. The grounds below the organic soil layer were sandy silty clays in stiff and firm state. Under those soils there were semi-compact medium sands, arranged in layers as shown in Figure 3 and 7. The ground water level was 0.7 m below the channel bottom. Geotechnical parameters of soils determined in field and laboratory analyses are presented in Table 1.

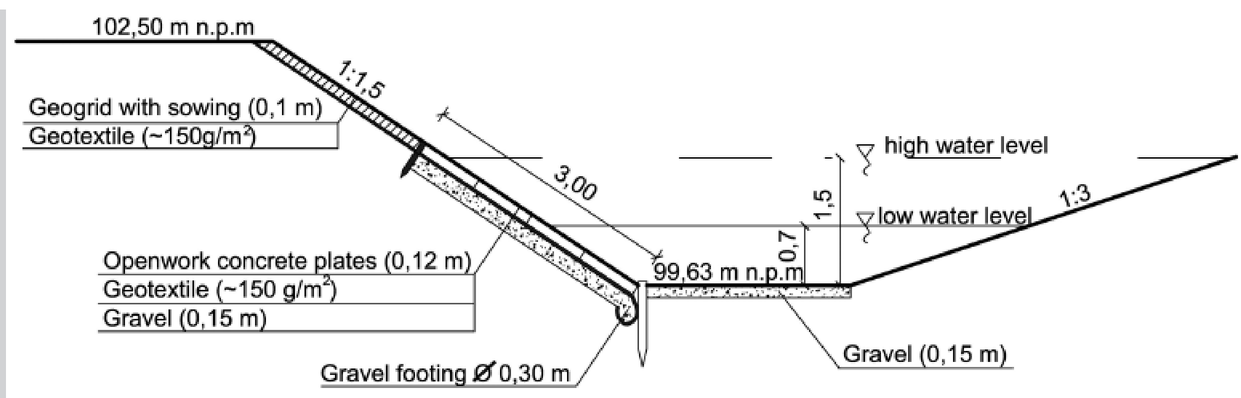

Figure 1.
Cross-section of the designed reinforcement of channel slope

Figure 2.
View of the slope after the failure (private collection)

Table 1.
Selected parameters of soils in the slope

Borehole number	Type of soil	Density index I_D [-]	Liquidity index I_L [-]	Unit weight γ [kN/m^3]	Coefficient of permeability k_{10} [m/s]	Internal friction angle ϕ_u [°]	Cohesion c_u [kPa]
1	sasiCl	-	0.39	19.00	10-11	12.00	31.00
	sasiCl	-	0.31	20.00	10-11	12.00	32.32
	MSa	0.46	-	19.00	2.10-4	35.00	0.00
2	sasiCl	-	0.10	20.00	10-10	19.00	32.00
	MSa	0.31	-	18.00	2.10-4	34.00	0.00

Based on obtained soil parameters, the slope stability for 2 most disadvantageous variants of circular slip lines location were calculated using the Bishop method. Determined safety factors equalled $F = 2.15$ and $F = 2.26$, so they were higher than the required value $F = 1.30$ (Fig. 3) [4]. This means that the gravity safety of the slope, even taking into account the load resulting from the organic soil stored nearby would not be destroyed (Fig. 3).

3.2. Analyses of applied anti-filtration reinforcements

Geosynthetic reinforcement and filtration materials are often applied uncritically, although in many cases they are not necessary and even lead to a deterioration of the structure stability conditions. This results from the lack of appropriate analysis that would allow for the adaptation of their material analysed case geotextile was used without conducting the required filtration analysis. The surface weight of one square meter of geotextile was adopted as the only criterion for selection [2]. The neglected factors included water permeability and the suitability of mesh size O_{95} to the granulation of the covered soils [3].

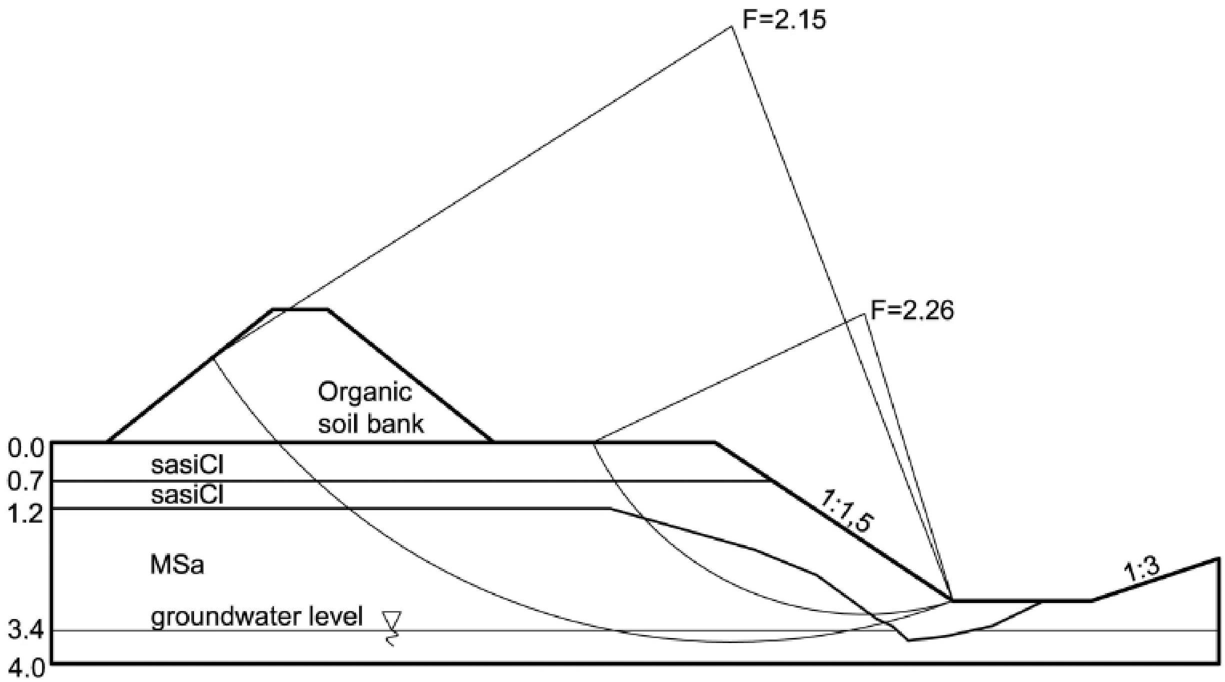

Figure 3.
Calculation scheme of the slope with most disadvantageous slip lines

In the upper part of the slope, a geogrid made from PEHD was placed above the geotextile, while in the lower part of the slope a 0.15 m thick layer of gravel was laid under the geotextile, covering non-permeable sandy silty clays. A gravel footing was formed at the base of the slope, on the side adjacent to the channel. It was covered by the geotextile, which made it impossible to effectively discharge the water from the gravel layer to the bottom of the channel (Fig. 1) [2].

The applied design solution did not take into account any analysis of usability of the geotextile in existing soil conditions, using the value of superficial mass of one square meter of geotextile as the only selection criterion [2], although it is not connected with water permeability. The contractor used Geocetex 200HTS geotextile [1] whose water permeability value specified in the catalogue equals 0.078 m/s and under a load σ_n = 20 kPa it decreases to 0.00053 m/s. With such parameters, the amount of water that could flow through the openings in concrete plates covered with geotextile (accounting for only approx. 30% of the total surface of plates) was lower than the amount of water infiltrating into the upper part of the slope.

For verification purposes, laboratory tests of water permeability were conducted on a sample of geotextile collected from the location of slope breakdown. Tests were performed according to the standards [6, 9] at a high hydraulic gradient i = 40 both for the

Table 2.
Results of tests of water permeability of the geotextile for water

Conditions of filtration	Hydraulic gradient i [-]	Flow time during the measurement t [s]	Average volume of water flowing in time t V_{wa} [cm^3]	Coefficient of permeability k_{10} [m/s]
through geotextile	40.00	30.00	241.40	$3.05.10^{-5}$

Table 3.
Results of tests of water permeability of the geotextile for clay suspension in water

Conditions of filtration	Hydraulic gradient i [-]	Flow time during the measurement t [h]	Average volume of water flowing in time t V_{wa} [cm^3]	Coefficient of permeability k_{10} [m/s]
Flow of clay suspension through the geotextile	40.00	8.00	8.57	$6.07.10^{-9}$

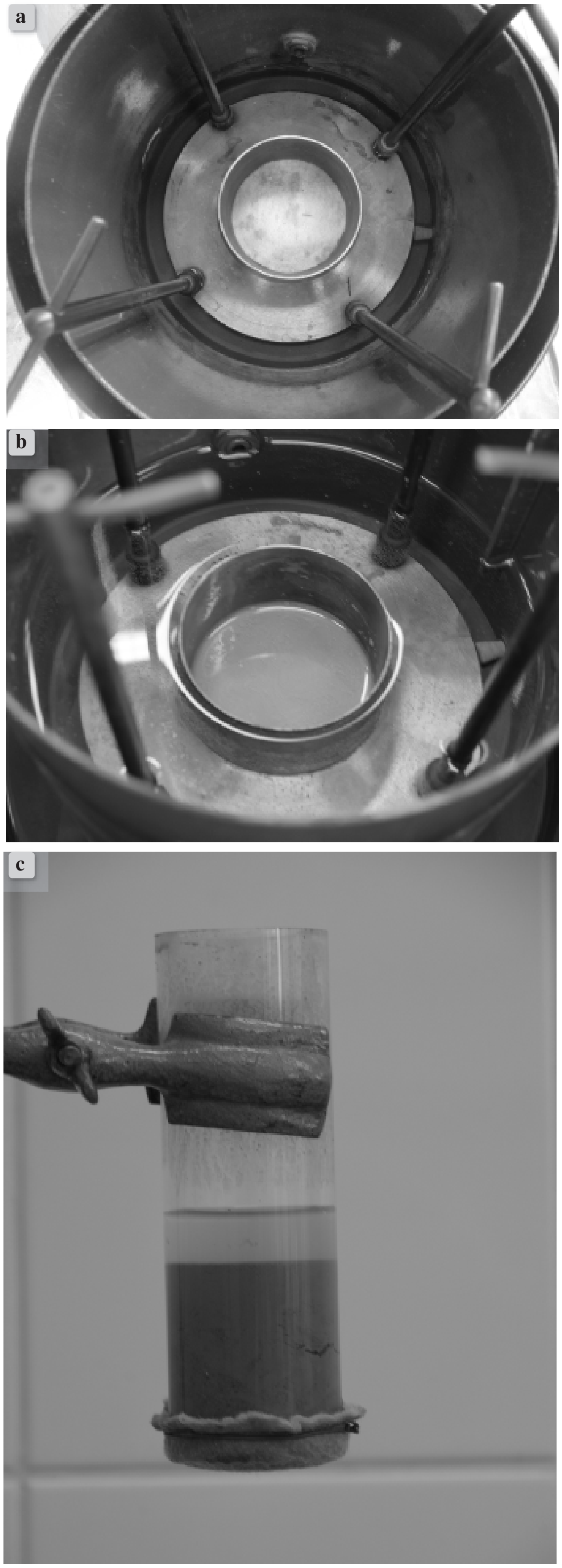

Figure 4.
Tests of water permeability of the geotextile; a) flow of water through geotextile; b), c) flow of clay suspension through the geotextile

geotextile alone (Fig. 4a) and in the conditions of possible clogging with water suspension of clay (Fig. 4b, 4c).

The values of filtration coefficient of the geotextile obtained as a result of the tests (Tab. 2) were significantly lower than data specified in catalogue that equals 0.078 m/s, [1].

In order to check the results of geotextile clogging, a suspension of clay in water was filtered through the geotextile (Fig. 4b, 4c), which demonstrated a significant decrease in water permeability (Tab. 3). For the purposes of comparison, the proneness of geotextile to clogging was also tested basing on the granulation criterion proposed in hydrotechnical construction according to Loudiere [3], where two following requirements should be met at the same time:

$$O_{95\,gtx} \leq 0.8\, d_{50}[\mathrm{mm}] \qquad (1)$$

$$O_{95\,gtx} \geq 0.05\, d_{50}[\mathrm{mm}] \qquad (2)$$

where:

$O_{95\,gtx}$ – diameter of geotextile mesh,

d_{50} – the size such that 50% of the particles are smaller than d_{50}.

Pursuant to data listed in catalogue, the analysed diameter of geotextile mesh equalled $O_{95\,gtx}$ = 0.08 mm [1], which does not meet the condition described by inequality (1) with respect to the analysed clay of an equivalent diameter d_{50} = 0.06 mm [4].

The conducted analysis confirms the result of the laboratory test that demonstrated that geotextile was clogged with the clay used in water and soil mixture.

4. DISCUSSION

Based on conducted research and analysis as well as considering the nature of the slope damage it was found that the failure started from the level where openwork concrete plates were laid on the surface of the slope. This occurred during intense rainfall (85 mm) on the surface of non-permeable soils. Taking into account the additional discharge of water from the heap of deposited organic soil (Fig. 3) it was calculated that approx. 15 dm^3 of water flowed down the surface of a 1 m long section of the slope during 48 hours. The water retained in the openings of the geogrid infiltrated into the gravel layer located in the bottom part of the slope (Fig. 5).

Figure 5.
Hollow space below the geotextile caused by moving the soil to the gravel layer located underneath the concrete plates (private collection)

Figure 6.
Openings in concrete plates with geotextile on the bottom side (private collection)

As the field and laboratory tests have shown the top layer of slope was built of clay (Tab. 1, Fig. 3, 7). Due to the clayey subsoil, discharge of water from gravel to the channel occurred only through the openings in concrete plates, which were covered with geotextile characterised by an insufficient water permeability coefficient (Tab. 2). In addition, conducted tests of clay suspension permeability through the geotextile (Tab. 3), as well as the computational analysis confirmed that in this ground-water condition the geotextile is prone to clogging. This resulted in an excessive water pressure below the open plates, which is proven by the displacements of geotextile in form of bulges in the plates openings (Fig. 6).

The resulting gradual soaking of the clay underneath the gravel led to a decrease in its strength properties, which in turn, caused a failure in the lower part of the reinforcement (Fig. 7).

In order to evaluate the results of soaking of clay characterised by a liquidity index $I_L = 0.10$, additional tests of strength parameters were performed on saturated samples. After saturation the liquidity index I_L decreased to $I_L = 0.37$, the value of the internal friction angle Φ fell from 19° to 13° and cohesion decreased from 32 to 20 kPa. With the additional contribution of non-dispersed excessive water pressure below the geotextile layer the obtained stability coefficient of the flat slip line was lower than $F = 1.0$.

5. CONCLUSIONS

1. Rainfall waters penetrating underneath the geotextile on a large surface, in the upper part of the slope, were impounded below due to the lack of discharge possibility in the lower part. This resulted both from too low permeability of the geotextile and from too small drainage surface of openings in plates.
2. Long-term soaking of cohesive soils located under the surface of poorly filtrating geotextile and gravel layer led to the softening of clays deposited

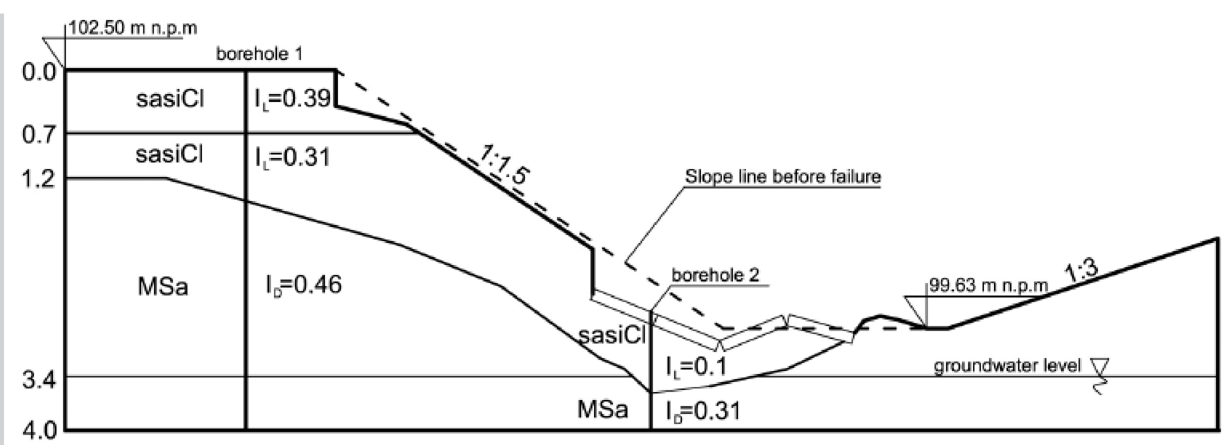

Figure 7.
Cross-section of the slope after destruction

under the slope drainage and thus to a decrease in their shearing strength parameters. This resulted in the failure of the lower part of the reinforced slope.

3. It was proven empirically that the applied Geocetex 200HTS geotextile was not appropriately selected with respect to the required water permeability. This resulted in the lack of ability to discharge water quickly through openings in concrete plates. Additionally, failure to meet the criteria of resistance to clogging by the geotextile confirmed the ineffectiveness of its application in the existing cohesive soils.
4. The discussed case is an example of the results of neglecting the principle of selecting geotextile in terms of the granulation of the drained soils in the design process.

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