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Stability analysis and flow behavior for dikes reinforced with geo plastics using numerical modeling

David Ioan[1] Banjac Robert[2] Ştefănescu Camelia[1]

Abstract: The focus of this work was the influence of two geo plastic reinforcement in dikes in terms of the flow behavior and thus examined the stability and possible erosion. Based on a parametric study, different models of dike, with representative reinforcement with geo-plastic materials were analyzed taking into account different groups of soil parameters. Here, the analysis was divided into a flow calculation and a coupled flow and stress analysis and subsequent stability analysis for two load cases. The analysis was performed using a finite element program.

1. INTRODUCTION

The practical experience in the past few years have shown that old dykes no longer match the State of the art and make a great danger for the environment so that they are urgently rehabilitated or new one to be built. In the new building and the rehabilitation of dykes, stability and economy in the foreground have priority. Important factors for the default security of a dike are the installation materials, as well as the training of the Bank next to the underground conditions.

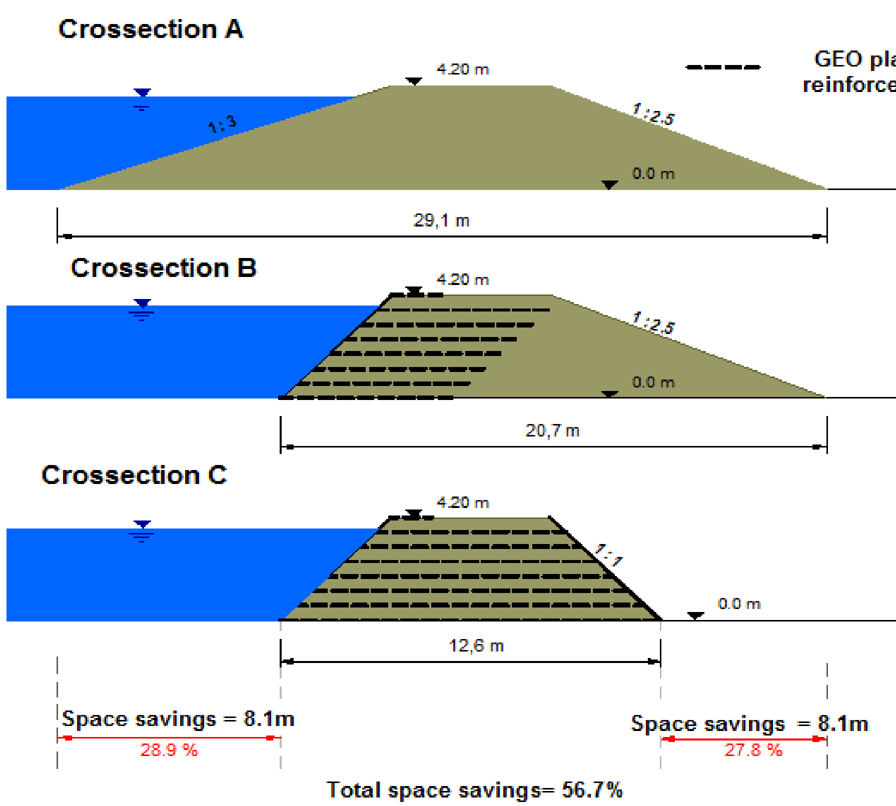


Fig. 1 Example of space gained by steeper embankment of dyke

[1] "Politehnica" University of Tmişoara, Faculty of Hydrotechnical Engineering,1A George Enescu St. 300022, Timişoara, Romania, ioan.david@gmx.net

[2)] Institut für Geotechnik, Eidgenössischen Technischen Hochschule Zürich

Through the use of geo-plastics is allows to build steeper embankment verges, which require a less usable

space, and require to another less Dyke material. This saves dyke construction materials and in closely limited space allows the renovation and the construction of dykes (fig. 1). The space thus obtained can return to the River.

2. STABILITY ASPECTS OF DIKES

During the construction and operating state is a dike through diverse, time-varying, inner and outer forces claimed. The dike and the surface form a unit. Because of this, the identification of external and internal influences on the dike and the surface must extend. If the dike not withstands these external and internal influences so it can be unstable. Here, the water pressures, waves, seismic vibrations, and traffic loads form the outer influences. The pore water flow, the pore water pressures and the water currents describe the internal forces.

To describe a dike system behavior, the likely instabilities of a dike were divided as follows:

- Macro instability when dykes (e.g. Bank broken)
- Instability in reinforced soil structures
- Micro instability (e.g. erosion, Suffusion, etc)

For dikes with pending flood, the most unstable on the embankment is, when the flow direction is the direction of the slide immediately. In the steady state, this is usually the air-side slope of a dike and falling water levels, the water-side slope this add up the flow forces on the slope-driven-forces of the slope.

Pore water pressure has a large influence on the default security of the dam or dike. The pore water pressure builds for example through a fast construction process of dike by fluctuations in water pressure mirror or suddenly occurring traffic loads on the dike.

3. PORE WATER TENSION BETWEEN SOIL AND GEO-PLASTIC

Low permeable or colmated geo synthetics (stored by soil particles), which are used as reinforcement in floor constructions, can reduce the reduction of pore water pressure or even prevent. This would mean that existing pore water pressure near the GEO plastic push away the soil grains of the GEO plastic and thus the shear strength between soil and geo-plastic decrements (see Figure 2).

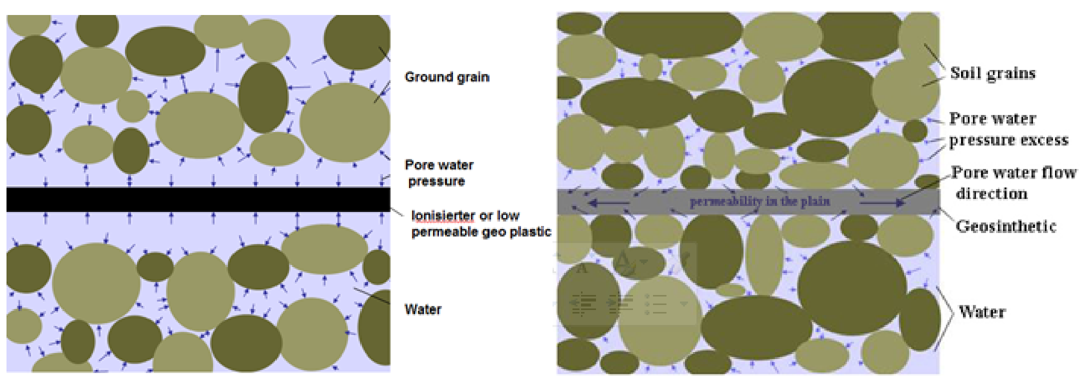


Fig. 2 a Press away the soil grains of the GEO plastic through the pore water pressure
b, Reduction of pore water pressure through the GEO plastic with permeability in the plane

Well-drained spatial plastics with permeability in the GEO-plastic plane can because reduction of pore water pressure accelerate (drainage effect) and increase the shear strength in this area.

4. MODEL APPROACH

A realized dyke construction project, on the coast of Holland, in which GEO-synthetics are used as reinforcement was taken as a basis for modeling. In this project, an existing dyke was extended or increased to counteract the higher rising flood. For reasons of space, a steeper slope on the side of the water needed to be constructed. These could be realized only with the use of sprinkle of geo-grids as reinforcement. A single axial stretched geo-grids was used the length of reinforcement the reinforcement spacing is 6.5 m long per layer is 0, 6 m.

Fig. 3 Influence of the pore water pressure on the stability of the water-side embankment

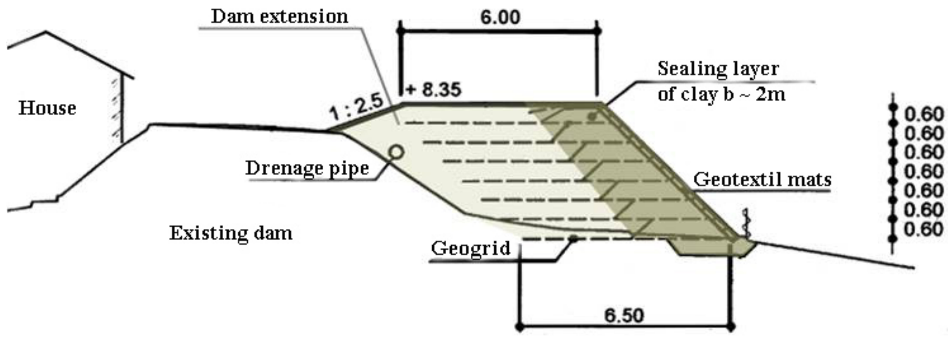


Fig. 3 Model approach: Dyke extension on the coast of Holland

To meet the State of technology at the dyke models the control profile of three Zone dike was used to modeling in addition as a basis (DVWK fact sheet 210 and DIN 19.712) (see Figure 4).

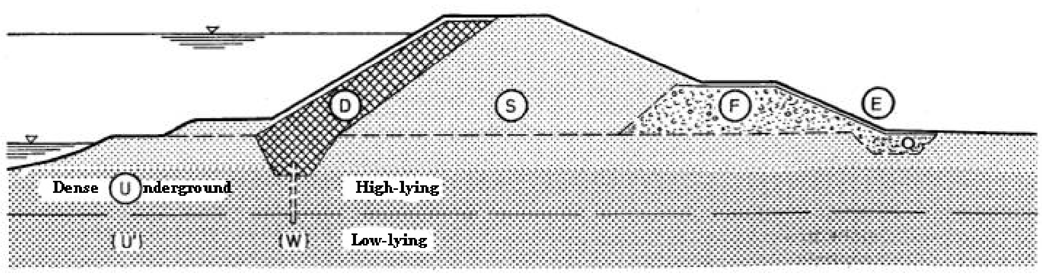
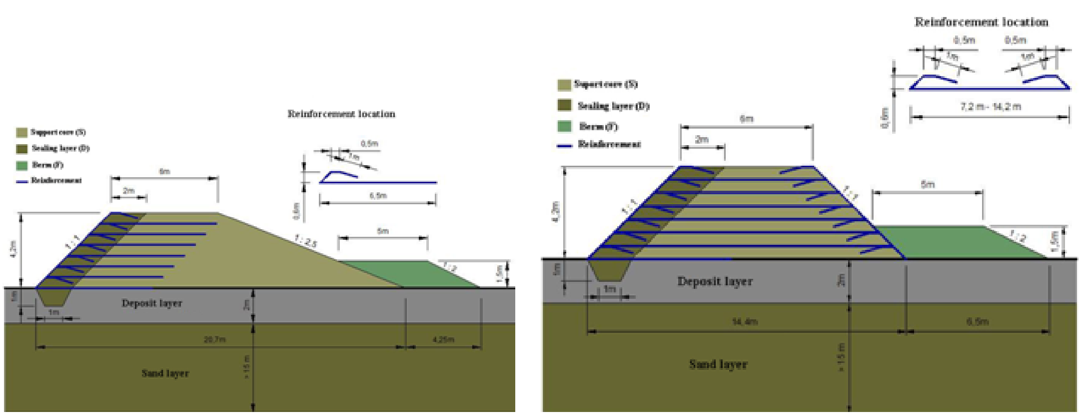


Fig. 4 Model approach: rule profile of a three Zone dike

Dyke cross section

Two dykes cross sections were examined for this work. Only the water-side embankment is reinforced with the first dike cross section. The air-side embankment was elected with a stable slope gradient of 1: 2. 5. With dike cross section 2 became the first cross section go expanded, that is the air-side embankment just as steep as the water-side.



Dike cross section 1, Dike cross section 2

Fig. 5 Dyke cross sections

Parameter choice

When the soil parameters for the Causeway (sealing layer and supporting core), two sets of parameters have been laid down. This should represent the first parameter set a floor with good bearing capacity properties and have a good opacity, so there may be higher flow rates. The second set of parameters is honed worse sustainable soils, which have a low permeability through the fine-grained. So will the flow duration, i.e. the length of time which needed until it reaches the air-side embankment (stationary state), extended the mirror line. Thus the unfavorably-acting fluid pressure for the air-side embankment can be delayed.

Soil parameters
Table 1

Parameter		Dyke parameter 1 Sealing layer	Dyke parameter 1 Supporting core	Dyke parameter 1 Sealing layer	Dyke parameter 1 Supporting core	Berme	Unterground Ablagerung-schicht	Unterground Sand layer
Durchlässigkeit	k_x [m/day]	0.00864	8.64000	0.00009	0.86400	86.40	0.43200	8.64000
	k_y [m/day]	0.00864	8.64000	0.00009	0.86400	86.40	0.43200	8.64000
	k_x [m/sec]	1.00E-07	1.00E-04	1.00E-09	1.00E-05	1.00E-03	5.00E-06	1.00E-04
	k_y [m/sec]	1.00E-07	1.00E-04	1.00E-09	1.00E-05	1.00E-03	5.00E-06	1.00E-04
Cellular number	e	0.11	0.22	0.09	0.15	0.37	0.11	0.18
effective porosity	n_{eff}	0.10	0.18	0.08	0.13	0.27	0.10	0.15
Moisture densities	γ_{dry} [kN/m³]	16	17	16	17	17.0	17.0	17.0
water-saturated goblins	γ_{wet} [kN/m³]	18	20	18	20	21.0	19.0	20.0
Modulus of elasticity	E [kN/m²]	25'000	80'000	15'000	50'000	90'000	20'000	50'000
Number of cross elastic	ν	0.330	0.300	0.330	0.300	0.300	0.330	0.300
Cohesion	c [kN/m2]	10.0	1.0	10.0	1.0	1.0	5.000	2.000
Friction angle	φ	25.0	37.5	20.0	32.5	40.000	27.500	29.000
Dilatanzwinkel	ψ	0.0	5.0	0.0	0.0	6.000	0.000	0.000

GEO-synthetics

Mainly an axial/biaxial geo-grids and high tensile Geo-textile are used for reinforcement of floor constructions. In this work, therefore these two types of geo plastic are used and examined. While the high tensile strength were selected Geo-textile and geo-grid products so that the design strength is roughly the same size. Both have a single axial reinforcement direction.

But, a part of the area of geo-grid surface is impermeable, a reduction factor for the permeability of the soil was calculated as follows, where a the permeability of soil adjacent to the geo-grids is. Open area of geo grid:

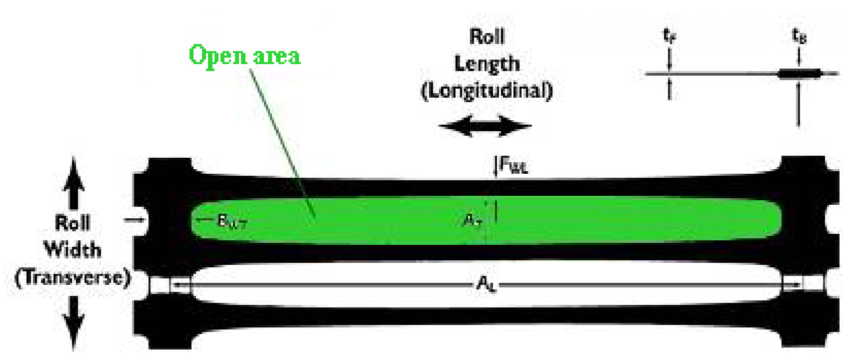


Fig. 6 Open area of geogrids

An open area 68%, a reduction factor of 0.68 for the opacity of the adjacent ground arises. Design strength and rated axial stiffness of geo plastic (according to recommendations for reinforcement from geo plastic - EBGEO) Geogrids Tensar RE 55 - max. Tensile strength = 64.5 kN/m^2

Geo-grids Tensar RE 55 - max. tensile strength = 64.5 kN/m2

Model overview

Dyke models 8 for stability analysis and 12 for calculating flow arise as a whole. 12 Embankment models are 4 Dyke models included were investigating only to compare without geo plastics on the flow behaviour in the table below is an overview of the dyke models with the corresponding short label shown (e.g., dike lattice P1).

5. FLOW CALCULATION

The design flood level (BHW), for the dyke models was proof set at 3.70, so that there is still a freeboard of 0,5 m. In the hinterland of the dyke of the worst water level (groundwater (GW) = area upper edge) assumed:

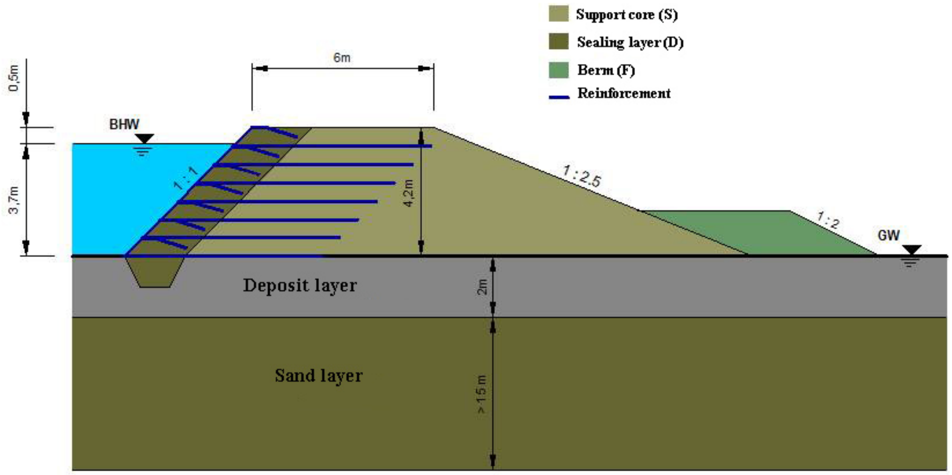


Fig.7 Design flood level (BHW) on the dike cross section 1 shown

In the embankment underground occur on the basis of its history, and the dike itself due to the construction process and sprinkle compaction work, anisotropic permeability ratios (k-x > ky). The current engine of PLAXIS with anisotropic permeability ratios, proved however unstable, i.e. however a recurrent history of mirror line arose that, so that isotropic permeability ratios were used. In PLAXIS, thin layers of soil were modeled to simulate of the spatial plastics and their hydraulic properties were then topped with the horizontal and vertical permeability values of the GEO plastics. For the vertical permeability of geo grid the surrounding soil by factor 0.68 is reduced to take account of the closed surface of spatial grid which is opaque

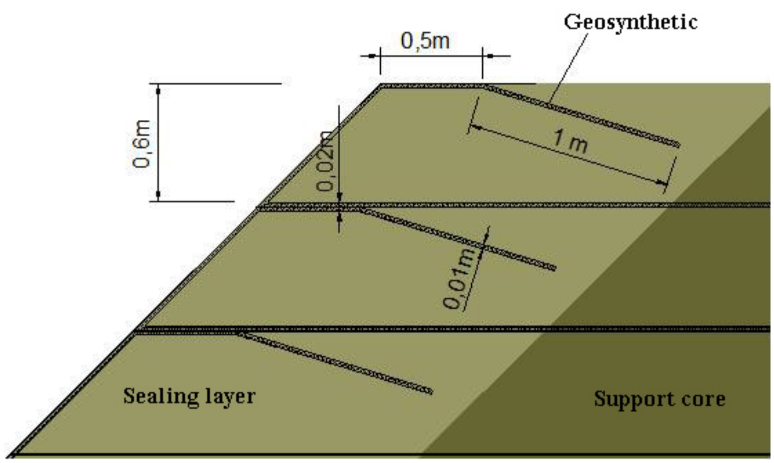


Fig.8 detailed drawing of the overlap area of the GEO plastics as they geometrically in PLAXIS have been modeled

Some results of the flow calculation

The size of a current vector is this equivalent to the great of the flow velocity. Due to the low speed of airflow in the sealing layer the flow vectors can be not represented. The mirror line history in the sealing layer of dam cross section 2, corresponds to that of the dyke section 1 high and is not represented here:

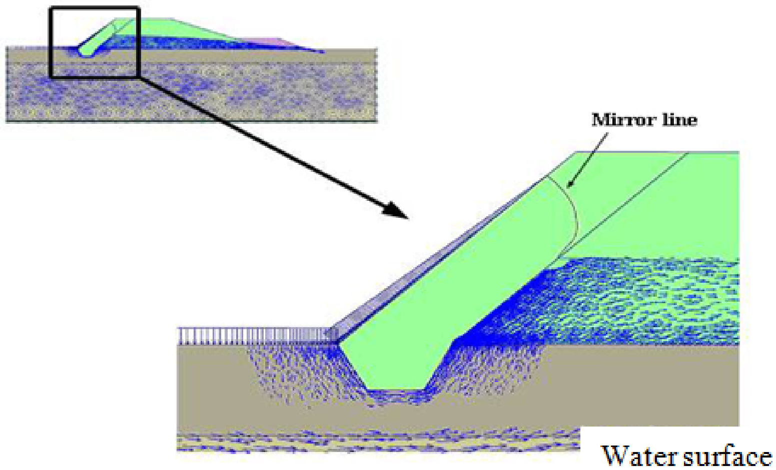
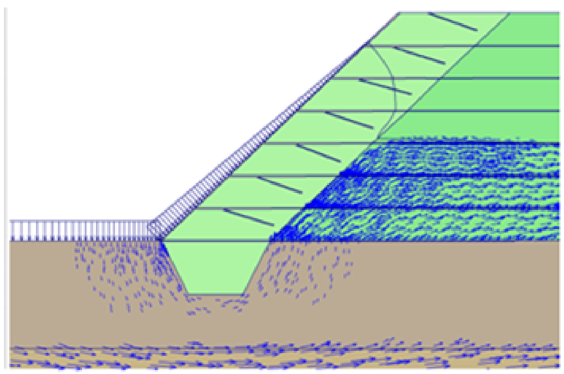
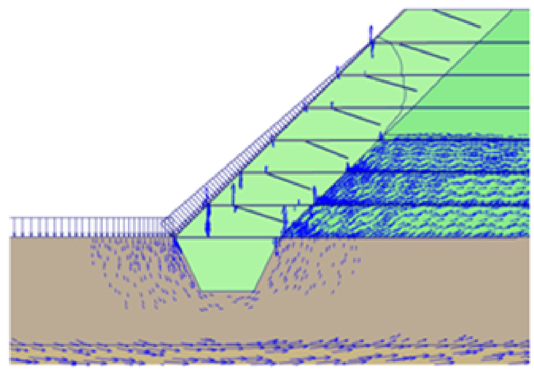


Fig.9 Detail sealing layer, flow vectors, not a geosynthetic



with geogrids



with geotextil

Fig.9 Detail sealing layer, flow vectors

6. STABILITY ANALYSIS

Stability analysis, two possible loading cases were examined:

Loading 1:
• No floods
• Live load on the dike crown

Loading 2:
• Flood
• Live load on the dike crown

As traffic load, a SLW 30, for the extreme cases, has been included on the dike crown according to DIN. It is a 3 m center used wide replacement surface load of 16.7 kN/m2.
The compression ratio of the individual layers of the soil and the resulting increased sustainability were considered in the choice of parameters through increased shear strength and stiffness. The horizontal tension increased pressure from the compression, which acts in the middle part of the dike could be excluded because there no way were these, e.g. by a raised Earth return coefficient, to simulate. The build process of sprinkle building, was simulated ("stage construction") phased. There were a total of 7 layers, each 0.5 m, built up the dike and the berm have reached the final. This installation time consolidation was account per location 1 day. The consolidation calculation was applied to the determination of stress during the construction period, and to take account of the pore water pressure. After all phases of construction of dike, the two load cases were used on 1 and 2. Following the stability with the PHI – C reduction was then determined. The entire calculation was performed with updated geometry of FE network ("updated mesh") because large strain is expected.
The Mohr-Coulomb model was chosen as material law for the soil, a linear elastic perfectly plastic stress-strain relationship is and so only an approximation to the real behavior is. However, deliberately no higher-quality material law was used, since in determining the stability with the PHI-C reduction in the higher-quality material laws be reduced to the Mohr-Coulomb model, i.e. that the voltage-dependent stiffness behavior of higher-quality material law reduces to the voltage-independent stiffness behavior. As here, however the frontier State, and not the proper

application examines the selected model considered sufficient will.

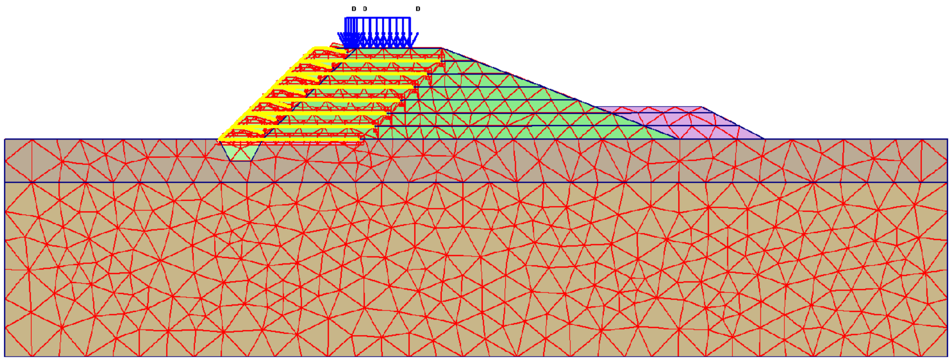


Fig. 10 FEM – Network, Dam cross section 1

Determination of the stability

The PHI-C reduction is a method that is used for the calculation of srability. In this method, we are the friction angle tan φ and the cohesion (c) of the soil gradually reduced until the failure occurs in soil structure. The safety factor thus determined is called Σ Msf and is determined as follows:

$$\Sigma Msf = \frac{\tan\varphi_{vorhanden}}{\tan\varphi_{reduziert}} = \frac{c_{vorhanden}}{c_{reduziert}}$$

This approach corresponds to the method for the calculation of safety coefficients that are normally used in calculating floating-point code is however not directly comparable.

Results - stability analysis

In the representation of shear strain of dike model, the formation of a sliding surface becomes visible. The airside shows regardless of the GEO plastic and parameter group, loading, 1 that failed the water-side embankment and 1,600 2.

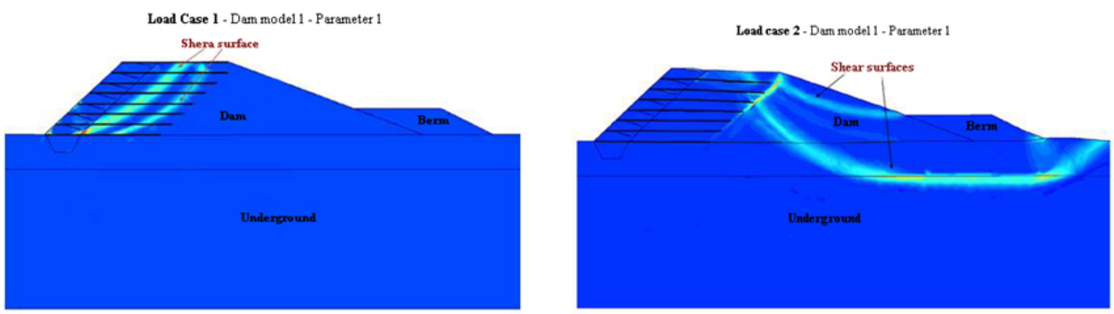


Fig. 11 Shear strain Deich1-tissue-p1-LF1 and LF2 respectively

7. EVALUATION OF THE RESULTS, CONCLUSION

The infiltration free water surface in the dike without or with geo-grids is almost identical. It is assumed that such an employed geogrids has no, or a negligible influence on the course of the infiltration water level. Unlike the geogrids in the fabric shows a limited impact on the free surface line and lets them in tissue due to the horizontal higher opacity, flow some more in the horizontal. This happens only in the sealing layer, because the difference in permeability between tissues and sealing layer is large.

Still, the flow vectors, in some places, show that the leach ate in the sealing layer occurs from the tissues. This can follow to have is between soil and geo plastic a pore water pressure builds, which from minder the friction between geo-synthetic and ground. This seems but only occasionally to enter in some places and will pose no apparent risk to stability. In the dyke section 2 a higher flow rate such as on the limit of geo plastic is reflected in the supporting core between the geo-plastic (fabric and geo-grids). This is where high flow rates occur in particular in the right third of the supporting core. In this area the danger of joint erosion is particularly large i.e. erosion channel education between geo-synthetic and ground.

From the flow calculations is to conclude that at the dike cross section 1, some modifications, such as drainage pipe in the berm, to expect the least with micro-instabilities is. Dike cross section 2 in particular with parameter group 1 shows on high flow speeds in the right third of the supporting core that makes a shadflies run off of leach ate in the nearby area of geo plastic difficult.

Generally, only indirect information about the micro instability of Suffusion and erosion will provide the FE calculation of flow because they are not considered for the essential for micro-instabilities soil characteristics such as e.g. particle size distribution. Only an indirect proof of the flow velocity and analytical evidence is possible an assessment of the Suffusion micro instability and erosion.

Through the live load, the water-side embankment, with the small sustainable seal layer failed expected unsuited to. A sliding surface through the layers of reinforcement is formed so how it is often observing in the reality. The hydrostatic pressure and the buoyancy effect of floods significantly increase the stability of the water-side embankment. Only with a certainty of about 2, with the dam cross section 1, failed the air-side embankment in a large body of break, including a berm.

The tensile stresses that occur in the GEO plastic are very low in relation to the maximum allowable tensile stress of geo synthetics.

The maximum tensile stress in the reinforcement by the PHI-C-Reduction indicates that the ground has failed, but the maximum tensile stress of the GEO plastics is not exhausted. These train power reserves of the GEO plastics prevent a complete failure of the embankment. The reinforcing liners are still the ground in this case.

The advantage of the PHI – C-reduction method compared to the conventional analytical investigations of stability (e.g. after Janbu, Bishop) is that the PHI – C-reduction method with consider the stiffness, and the of him dependent deformation, and the stress history of dike. Still, construction processes, complex geometric constructions and load impact (current and live load) be considered in a coupled context. The effect of different load impacts, such as pore water pressure and flow pressure, are taken into account this FE calculation. However, it is also to keep in mind that other soil characteristics, such as for example the stiffness in the PHI – C reduction not is reduced as the shear strength. Another critical and crucial point the PHI – C-reduction method is that is the reduced friction angle the angle of the sliding surface is reduced and thus the floating wedge flattens itself and which pushes the sliding contact surface from the area of the reinforcement. This no longer reflects the real fracture mechanism. This would mean that more volume located in the floating wedge and therefore more volume and weight would be available. The flatter sliding wedge changed the transmission of power at the intersection of geo-synthetic and ground sliding contact surface (see the following figure).

To note is that not all mechanisms such as micro stabilities or pulling out of geo plastic can be simulated with the FE calculation. This applies above all the micro stabilities, which play a large role in a dike. This showed in reality, such as for example the erosion in different forms, that they can be the reason for the failure of a dam. The deformations that here were calculated are not to view to expected deformation. As was expected in the border State. Des was more a design strength at the GEO plastic design stiffness and used thus built a security was not applied when a use suitability for viewing.

Note

The paper was edited mainly by Mr. Bajak, during of his master at the University of Applied Sciences Suderburg, Germany under led by Prof. David. The master´s degree was an e-learning co-operation Project between Univ. Hannover and University Darmstadt where the Groundwater modeling lectures were held by Professor David.

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