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STABILISATION OF RIVER DYKES WITH DRAINAGE AND STABILISING ELEMENTS

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ABSTRACT: During floods dyke failures combined with considerable damage have been a common occurrence in recent years. Besides extreme meteorological conditions, ageing and a bad design of dyke structures must be considered as main reasons for failures. Any overall rehabilitation of the dyke systems can only take place on a long-term basis due to the considerable costs. Techniques for short term refurbishment are necessary. Therefore innovative geosynthetic structures and stabilisation techniques are developed to improve the stability through the mechanical installation of drainage elements, thus preventing dyke failure by controlling the seepage in the structure. Furthermore, reinforcement and suction effects caused by the drainage will probably increase the safety and these need to be quantified.

To ensure later industrial implementation, besides the verification of feasibility, design manuals have to be provided. Therefore the necessary data basis is created by numerical parameter studies. Results of hydraulic calculations like the location of seepage surface and pore water pressure are provided as input data to carry out stability calculations. Calculation results are verified by model tests in the laboratory and by means of a dyke model on a technical scale, where the installation of drainage elements is carried out by a standard drilling crawler.

Key Words: Geosynthetic drain elements, slope stabilisation, dyke failure, reinforcement

1. INTRODUCTION

In order to achieve the defined targets, the joint project is divided into three main sections - Hydraulics - Stability - Drainage Elements - each under the responsibility of one partner. The University of Karlsruhe is investigating the hydraulic impact of drainage elements on the seepage regime in the dyke structure. The University of Kassel is quantifying the effects on the stability of the drainage elements, particularly by lowering the seepage surface in the structure, by reinforcement and suction. The task of the STFI is to create drainage elements which are cost effective and do not require much installation effort. The data exchange between project partners is supported by predefined interfaces.

In figure 1 the above mentioned technology is shown in a principle sketch. The different aspects of the project are discussed in more detail in the following chapters.

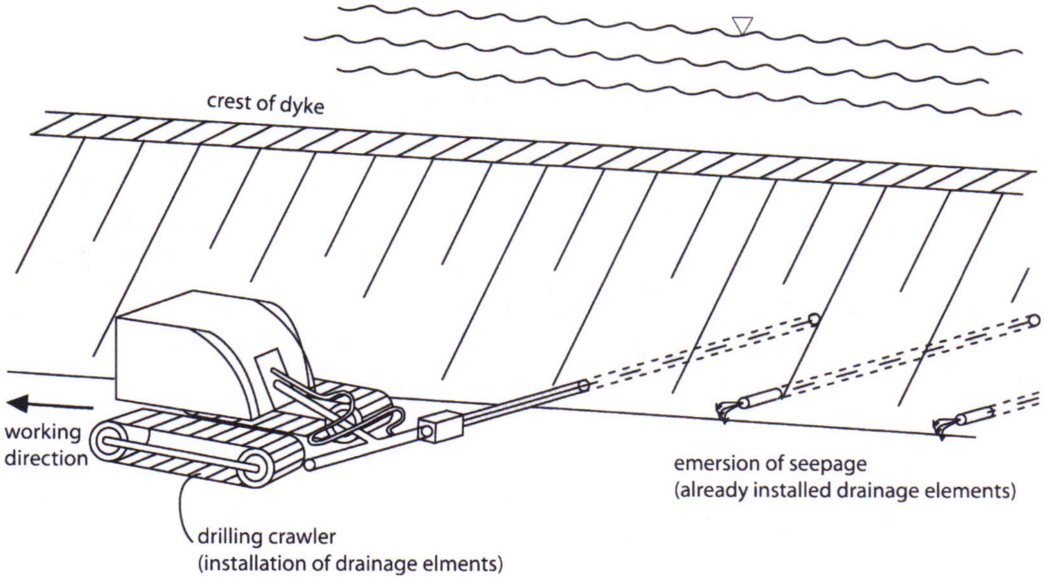


Figure 1: Stabilisation of river dykes by means of installed draining elements (principle sketch)

2. HYDRAULICS

One main aspect of the research project is to develop an engineering method in order to enable the applicant to design the improvement of river dykes by means of drainage elements (cf. figure 1). Taking the hydraulic impact into consideration, different working stages have to be carried out in order to achieve this aim.

Basic numerical calculations (2D- and 3D-calculations) confirmed the essential lowering capacity of drainage elements with a defined length and diameter to be arranged at regular intervals near the foundation of a river dyke. According to figure 2 a considerable lowering of the water table due to the installed drainage elements can be seen.

After verifying the numerical calculations - in particular the modeling of the drainage elements - a numerical parameter analysis was carried out by means of small scale hydraulic model tests. The effects of varying lengths and distances of drainage elements on seepage and draining capacity were examined. The geometry of the dyke structure was defined according to the conditions of aged dyke structures in Germany. The hydraulic load on the upstream slope corresponds to a water table at crest level. The dyke structures were assumed to be more or less homogeneous and soil parameters were predefined. Parameter analyses were carried out for either sandy or loamy dyke structures.

The results of the numerical parameter analyses were transferred to the partner project at the University of Kassel to analyze the effects on stability. 3D-data of pore water pressure distributions and locations of the phreatic surface were provided for stability calculations.

Slotted PVC-drainage-pipes - 2 inches in diameter - are considered as standard drainage elements. Besides their cost effectiveness PVC-drainage-pipes can be employed for a wide spectrum of soil materials. According to the experimental filter criteria the slot width has to be adapted to the soil material in order to prevent negative erosion effects.

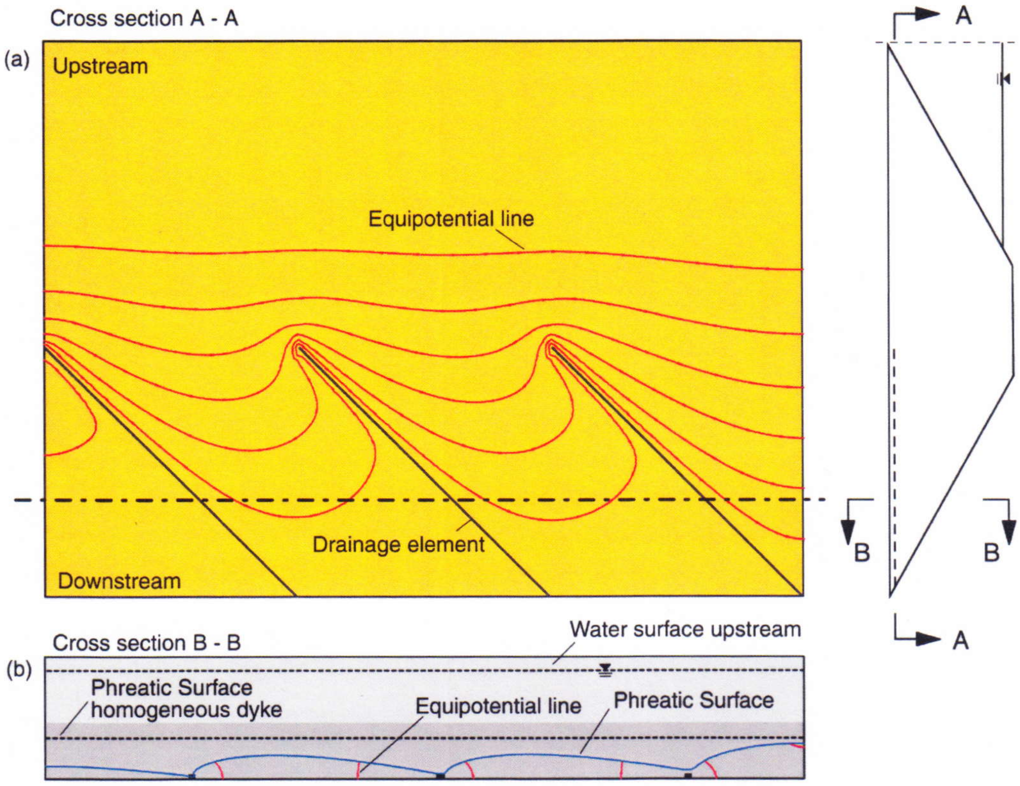


Figure 2: Lowering water table capacity of draining elements - horizontal section at foundation level (a) and cross section B-B (b)

A suitable installation technique adapted to the chosen drainage elements is an important aspect for ensuring the feasibility of stabilizing quasi-homogeneous dyke structures with drainage elements. The basic requirements of a suitable installation technique are cost effectiveness, the possibility of horizontal installation at a minimum height above the dyke foundation and minimum influence on the drainage capacity of the drainage element.

To verify both the feasibility of the stabilization technique and the hydraulic performance of drainage elements, tests were carried out by means of dyke models on a natural scale. The geometry of the dyke models was identical to the boundary conditions of the numerical parameter study. In the first step different installation techniques were tested on a dyke model with a standard drilling crawler (cf. figure 3a).

After determining a suitable installation technique, one drainage element was installed in a flooded dyke model on a natural scale under stationary seepage conditions (cf. figure 3b). Multiple measurement devices such as TDR-Sensors (Scheuermann *et al.* 2001, Woersching *et al.* 2006, Scheuermann *et al.* 2008) and tensiometers among others permitted a spatial investigation of the seepage inside the dyke structure. Special interest lay on the investigation of the potential development of negative pore water pressures while installing the drainage element, as well as on the hydraulic performance of the drainage elements and spatial effects on the phreatic surface. Measurement data was also used for a final verification of the numerical calculations.

The results of the various working stages will be published in detail in the future.

a) b)

Figure 3: Investigations on dyke models on a natural scale: a) Installation of drainage elements
b) Dyke model on a natural scale for tests with hydraulic load (view to downstream slope)

3. STABILITY

Three main factors, which may influence and increase dyke stability, were investigated in this joint research project. These factors are in detail:

- The lowering of the seepage line and the simultaneously changing of the specific weight of the soil material.
- A reinforcement effect of the draining elements.
- The suction effect due to the lowering of the seepage line.

As the research has not yet been completed, only the reinforcement effect of different draining elements will be described in detail in the following.

Reinforcement effect of draining elements

One of the aspects investigated was the determination of the reinforcement effect of different drainage elements. Large scale shear tests with three different types of drainage elements (table 1) were carried out in a shear test box, which was specially built for this purpose (figure 4, cf. Seeger *et al.* 2005). As drainage elements are usually not prestressed, the test series was performed without any prestressing.

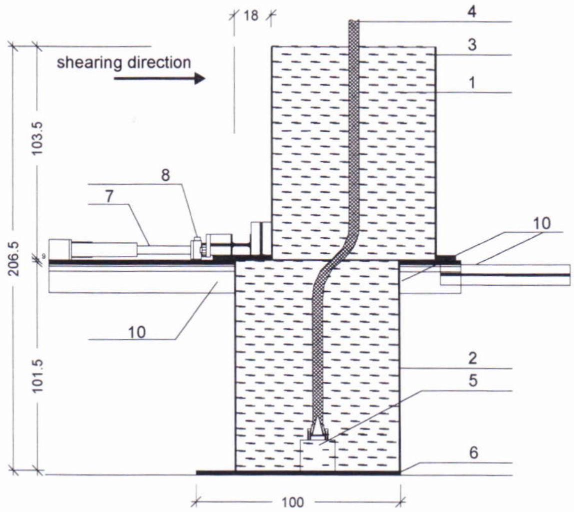
Table 1: Material properties and classification according to the flexibility of the analyzed elements

type	flexibility	flexural rigidity EI	axial stiffness EA	dimension in mm
"Dochtdrän"[1]	high	0	----	≈ 35 - 40 mm
PVC-pipe	medium	0,058 kN/m^2	513 kN	32 × 1,8 mm
steel-pipe	low (rigid)	2,87 kN/m^2	28140 kN	30 × 1,5 mm

[1] German name for very flexible draining elements, rope-like wick drain

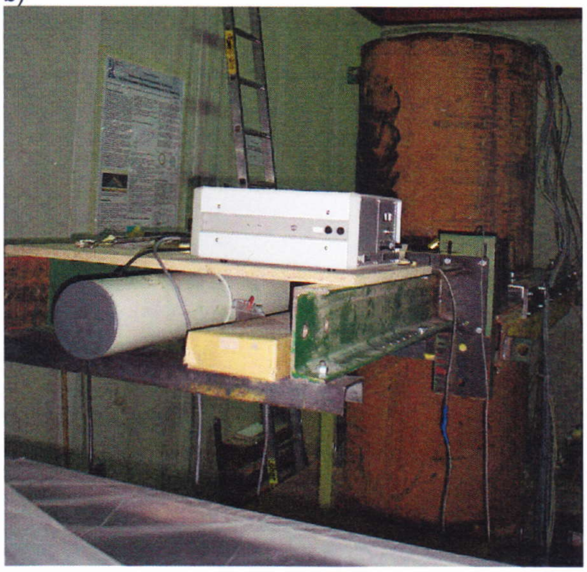
A well-examined medium grained sand was used as a specimen (without any drainage element). The sand specimen was prepared by a special sand raining technique according to Rad/Tumay, 1987.

a)



dimensions in cm

b)



1	test specimen	2	lower, fixed cylinder	3	upper, moveable cylinder
4	drainage element	5	possibility to fix the element	6	bottom plate
7	piston	8	load cell	9/10	auxiliary construction

Figure 4: Large scale cylindrical shear box - a) diagram and b) picture

In figure 5 the load displacement curves for the examined drainage elements as well as the results of reference tests without any element are shown.

With regard to the results shown in figure 5 it can be stated:

- Very flexible draining elements raise the load displacement curve slightly only after large displacements (approx. 50 - 100 mm). This could be explained by a slight increase in the normal tension in the area of the shear plane due to friction bond of the elements, because the drainage elements are unable to carry bending moments.
- Rigid and medium rigid drainage elements lead to a significant increase in the measured load compared to equal displacement in the reference tests, independent of the absolute displacement. This behaviour is due to bending resistance associated with the ability to carry bending moments.

Based on these first results, it can be stated that very flexible elements do not noticeably influence the load displacement behaviour. As the draining elements were not prestressed in the tests described, further investigations, e.g. with prestressing, need to be carried out in order to consider the reinforcement effect of different types of prestressed draining elements.

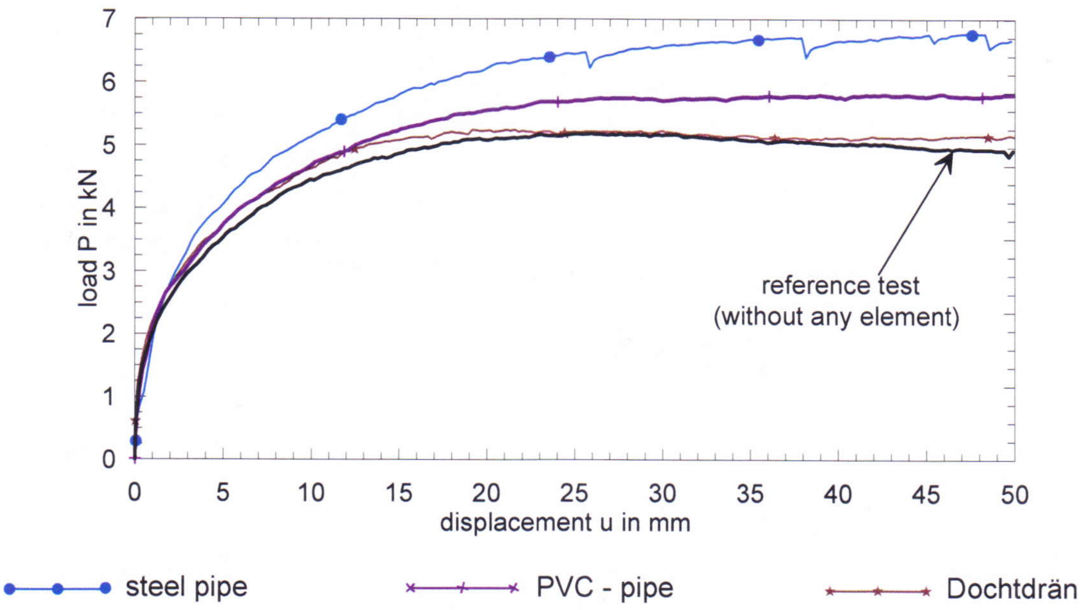


Figure 5: Load displacement curves for the materials investigated

Once more, it should be noted that only the reinforcement effect of draining elements has been described in this paper. However, the influence of the elements on the lowering of the seepage line and other effects caused by drainage, such as suction, is also important and should not be neglected in this discussion.

4. DRAINAGE ELEMENTS

The investigations and developments were focused on 2 different types of drainage elements:

- Standard drainage elements modified to achieve reinforcement and filter stability by combining plastic tubes with a textile filter layer and load bearing elements.

- Special textile stabilizing drainage elements with a maximum diameter of 300 mm (developed in the research project).

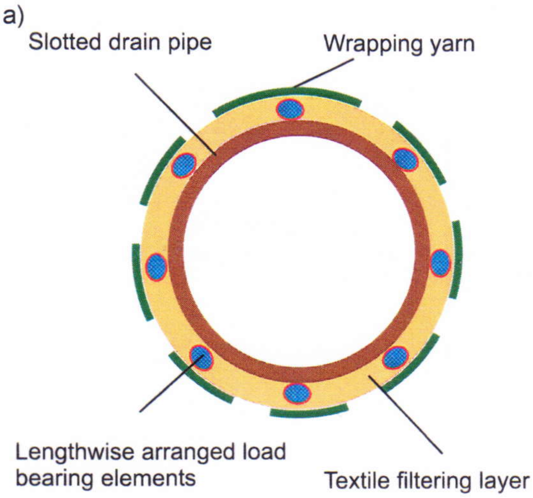
A number of different samples were developed and tested in the STFI laboratories in Chemnitz. Some of these drainage elements have been selected for installation for practical tests, which are still in progress.

Standard drainage elements combined with special textile layers

Standard drainage elements such as plastic tubes might be prone to colmation. By sheathing them with a filtering layer, the hydraulic function of the drainage elements can be assured.

Figure 6a shows the cross section of a modified slotted drain pipe sheathed with a special textile filter layer and load bearing elements inserted. To manufacture these drain structures, a special rope producing technology was used (cf. figure 6b).

a)



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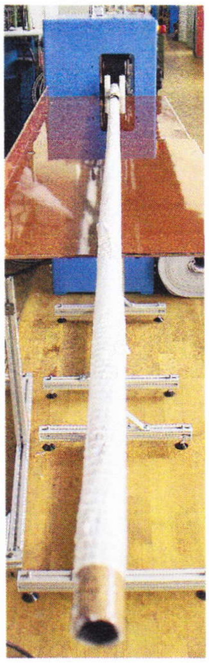

Figure 6: Modified drain element

a) Schematic cross section and constituents (slotted drain pipe)

b) Manufacturing of a modified drain pipe sheathed with a textile filter layer

Special textile rope-like drainage elements

To manufacture these innovative rope-like drainage elements (cf. figure 7), a novel textile manufacturing technology has been developed. As far as the manufacturing process on a special textile machine (cf. figure 8) is concerned, every kind of strip-like or cut material as well as fibers etc. can be used as raw material, even recycled industrial waste, in order to save costs (see http://www.sl-spezial.de/de/kompetenzen_kemafiltechnologie.htm and Seeger *et al.* 2003).

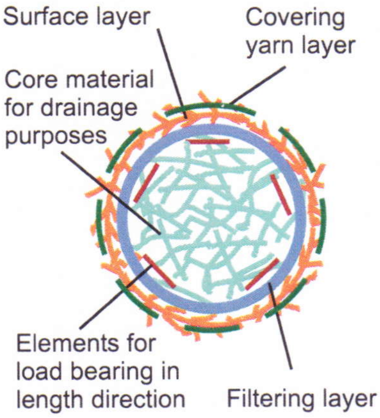

Figure 7: Innovative rope-like textile drainage element - schematic cross section showing constituents

Table 2: Constituents of geotextile drainage elements shown in figure 7 and their function

Constituent	Function
- Surface layer	- to improve adhesion to the surrounding soil
- Covering yarn layer	- to tie up the whole structure
- Filtering layer	- to prevent colmation or erosion
- Elements for load bearing in lengthwise direction	- to increase tensile strength
- Core material	- drainage material with high porosity

The basic prerequisite for trouble-free production is to use processable material, which can be fed properly into the manufacturing unit. In this way it is possible to produce rope-like structures made of a wide variety of materials in diameters of up to 300 mm. The hydraulic characteristics depend on the structural characteristics as well as the maximum tensile strength (Seeger *et al.* 2005).

For manufacturing purposes a modified commercial rope producing machine was used. Figures 8a and b show the processing and winding units. For tailored lengths another modified machine version was used, as shown in figure 6b.

a)

b)

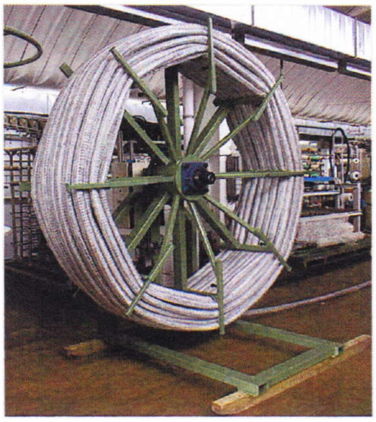

Figure 8: KEMAFIL® technology for manufacturing rope-like structures
a) Processing unit b) Winding up a coil

Depending on the installation conditions, the manufactured textile drainage elements can be either cut into pieces of the required length or wound up as coils (figure 8b). In the tests for the stabilization of river dykes, these drainage and stabilising elements were installed for the purpose of investigation. These coils can be put on a stitcher and installed in the ground for other potential applications, for instance as vertical drains *(*Seeger *et al., 2005).*

5. SUMMARY

Innovative stabilisation techniques and structures have been studied for short term refurbishment and improvement of existing and endangered dyke structures. The following possible causes have been investigated in detail: the lowering of the seepage line, reinforcement and suction effects due to drainage elements.

The investigations were focused on different types of drainage elements, namely modified standard drainage elements and innovative textile compound structures. To manufacture the latter a special rope-manufacturing technology was used.

Basic numerical calculations confirmed the lowering capacity of drainage elements with differing lengths and diameters. These results were used for 3D-stability calculations to determine the effects in terms of a parametric study.

An important aspect to ensure the feasibility of stabilizing dyke structures with drainage elements is a suitable installation technique adapted to the chosen drainage elements (basic requirements: cost effectiveness, possibility of horizontal installation at a minimum height above the dyke foundation). Therefore tests were carried out by means of dyke models on a natural scale.

To determine the reinforcement effect, large scale shear tests were carried out. With regard to these results it can be stated that there is no noticeable reinforcement effect of very flexible elements. For elements of this kind the reinforcement effect should be ignored in stability calculations.

6. ACKNOWLDEGEMENTS

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