ANALYSING THE RESISTANCE OF DIKES AGAINST EROSION DURING DIKE OVERFLOW

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Abstract:

The flood disasters of the past years emphasize the significance of effective flood control measures. The structural safety and the height of the dikes are crucial for a successful protection against floods, as river and sea dikes are often older than 100 years and haven't been redeveloped. From floods in rivers it is known, that the bad condition of the dikes may lead to enormous damage (e.g. the Elbe flood in 2002); however, the condition of the dikes is also crucial for sea dikes during storms.

During extreme floods sections of the dike line may be overflown. Usually this leads to the complete collapse of the dike due to erosion, one of the most common reasons for dike failure. This study investigates the suitability of innovative materials like recycling material and geosynthetics. The materials are used to construct and remediate river dikes and analyse their stability and resistance against erosion during sustaining floods and dike overflow. The investigations, which are part of the national research programme "Risk Management of Extreme Flood Events (RIMAX)" funded by the BMBF, are conducted at a full scale research dike. The dike is exposed to (1) the enduring forces of water pressure and percolation during spreading and (2) the shear stress during dike overflow.

I. EXPERIMENTAL SET-UP

The dike section was built with a core made of recycled material in a preliminary project. At that time we analyzed the pollutant discharge of recycled material during a long-term flood (AZ: 18063, 2005).The experimental area is located at Biebesheim am Rhein, Germany.

The dimensions of the dike section match to those of an average dike along the river Rhine. Its length is about 60 m, the width 17.5 m (base) and it has a height of 3 m and an inclination slope of 1:2.5. Thus, our experiment is a realistic in situ test of the dike properties during overflow.

At the landside of the dike there is a backwash of 5.0 m width. It leads to a propeller pump which delivers 4.7 m^3/s on a height up to 5 m and grants a closed water cycle within the experimental set-up.

Beside of the closed sheeting a sealing foil avoids the loss of water during the filling and the experiment. It is fixed at the top of the sheeting and proceeds under the dike base.

It takes about 5 days to pump the water needed for the experiment from a well nearby. The whole ponding area and parts of the backwash (up to 1 m from the ground) have to be filled in the forehand of the experiment.

The dike is partitioned into two exploration areas of 20 m width each. These areas are protected by geosynthetics, laid-out from the dike crest over the backwash to the landside sheeting and fixed by numerous pegs. The protection is extended by 1 m on both sides (to 22 m).

To avoid fringe effects (like scours at the wall or the protection boarders) a vegetated sector divides these two areas from each other and from the sheeting.

The height of reachable weir heads depends on the width of the overflow. If there is only one area overflowed at a time and if the top is constricted by sandbags, weir heads up to 1.0 m may be reached (Figure 3). In nature a dike heightening with sandbags has to collapse to cause such weir heads. Such catastrophes are not object of our current investigations so we restrict the maximum weir heads to 0.3 m.

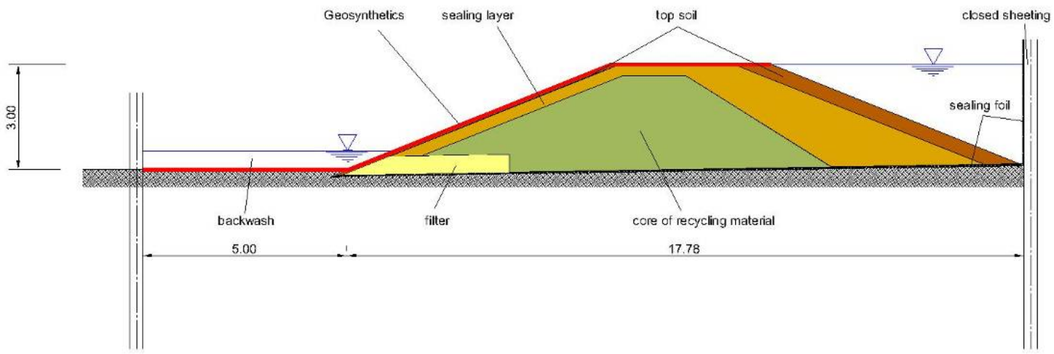

Figure 1. Profile of the experimental dike

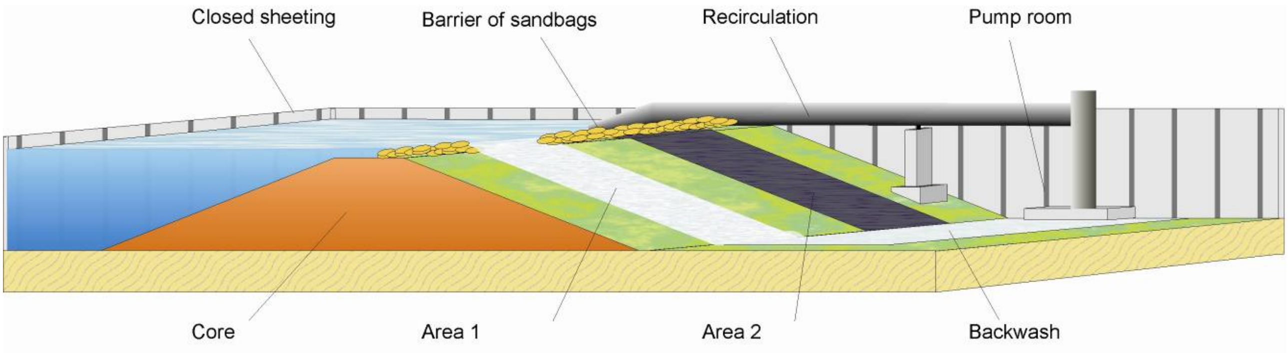

Figure 2. Elevation

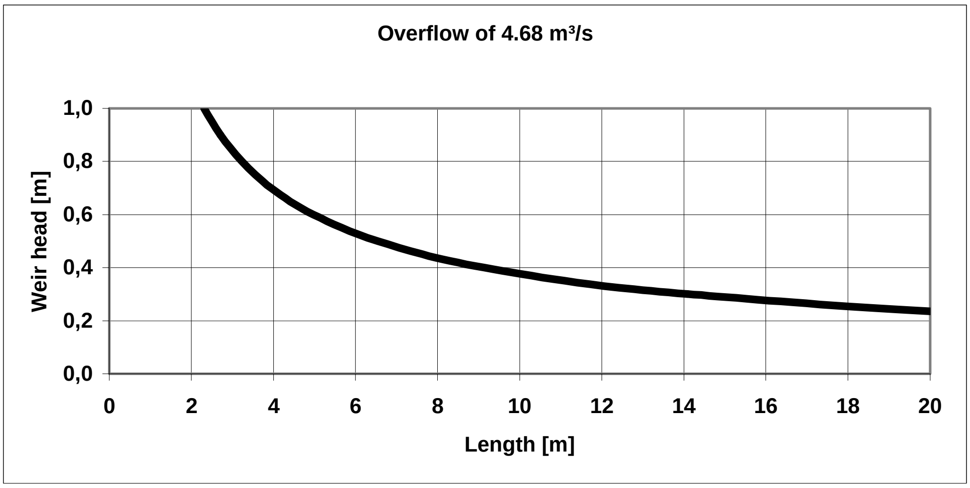

Figure 3. Overflow depending on the width of the overflow

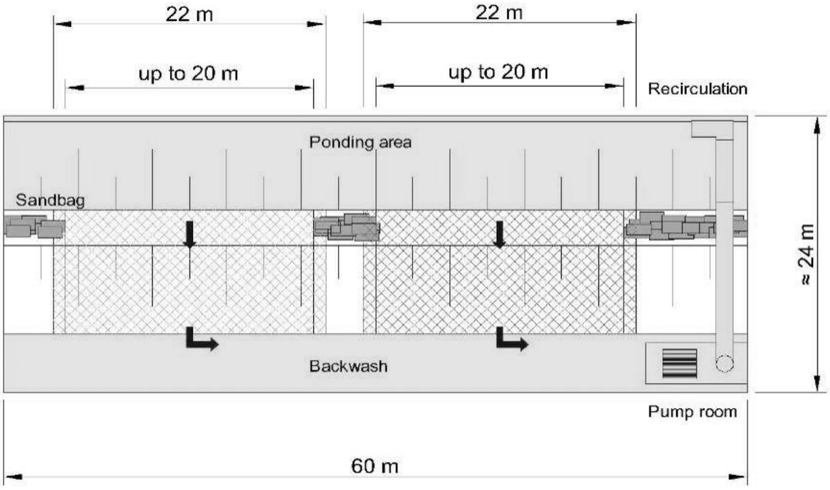

Figure 4. Layout of the experimental set up

A tube with an inner diameter of 1.4 m (DN 1400) effects the recirculation of the water. The flow velocity is about 3.04 m/s. A concrete surface (5 m x 2 m) and an additional protection by geosynthetics on the dike avoids a scour at the outlet. During the experiment, the estimated flow velocity parallel to the dike is about 0.4 m/s. In the backwash area a water level of 1.0 m has to be ensured constantly to minimize the risk of cavitation.

Because of the two experimental areas, it is possible to test different revetments or to build one area while the other one is tested. Apart from that we have the option to run a long-term and some short term experiments next to each other.

II. Hydraulic calculation and dimensioning of the bank revetment

Based on a slope of 1:2.5 and a Strickler-coefficient of k_{st}=50 $m^{1/3}/s$ (CIRIA 1987), Figure 5 shows the flow depth h and the average flow velocity v against the specific flow q (m³/s/m) (Steuernagel 2008).

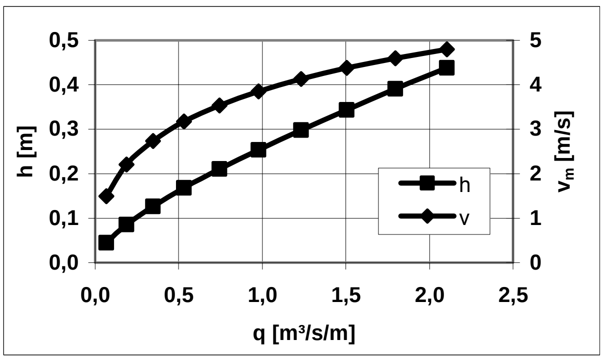

Figure 5. Diagram showing flow depth and velocity

The decisive factor for the erosion of the surface is the resulting bed shear stress τ_0, caused by the overflow.
The bed shear stress depends on the slope and the flow depth:

The maximum resistance of an unprotected patch of grass is about 18 N/m² or 30 N/m² if the strain is just temporary (Schneider 2006).

$$\max \tau_{0(bottom)} = \rho \cdot g \cdot h \cdot I_E \tag{1}$$

ρ: density of water [t/m³]
g: gravity [m/s²]
h: flow depth [m]
I_E: slope of hydraulic gradient [-]

The estimated shear stresses on the dike surface exceed these maximum values by far (see Table 1). Because of the slope of a dike, the active shear stress already exceeds the critical bed stress even if there are only slight weir heads.

This problem occurs more frequently at river dikes because of the flatter slope of the sea dikes. However, with rising weir heads this also becomes a problem for such flat dikes.

TABLE I.
BED SHEAR STRESS, WEIR HEADS AND THE SPECIFIC FLOW

weir head	dike crest discharge per m	flow depth on the landside (iterated)	average flow velocity	Froude number	bed shear stress
h_0 [m]	q [m³/s/m]	h [m]	v_m [m/s]	Fr	maxτ_0 [N/m²]
0,10	0,067	0,025	2,66	5,37	98,10
0,20	0,188	0,048	3,92	5,71	188,35
0,30	0,346	0,070	4,94	5,96	274,68
0,40	0,532	0,092	5,79	6,09	361,01
0,50	0,744	0,114	6,53	6,17	447,34
0,60	0,978	0,137	7,14	6,16	537,59
0,70	1,232	0,159	7,75	6,21	623,92
0,80	1,505	0,182	8,27	6,19	714,17
0,90	1,796	0,205	8,76	6,18	804,42
1,00	2,104	0,229	9,19	6,13	898,60

This table is based partly on literature and partly on assumptions. The actual data will be recorded by various water gauges and speed indicators (acoustic Doppler velocimeter (ADV), screw current meter). We will detect the deformation of the dike with area scanners and are at the moment verifying whether strain gauges can be attached to the geosynthetics. The perfusion (percolation from the ponding area and infiltration from the surface) will be determined by pressure gauges. The perfusion increases the danger of slope failure and slipping of the top soil.

III. ANALYSIS OF DIFFERENT BANK REVETMENTS

In order to decrease the danger of erosion and breaches (downcutting) and to avoid the raising of a dike it is important to improve the general resistance against the overflow of dikes.
An extensive application of protection against erosion requires an effective and low priced solution. This includes the costs for the material and the building costs. The protection should not only be applicable for a new dike but also for remediation measures. Therefore the erosion control should be embedded near the surface of the landside and/or at the dike crest. Intervention in the core or the sealing should be an exception.
Most experiments carried out on revetments so far have dealt with revetments on regular overfalls for detention basins or polders. Therefore these revetments are mostly not applicable for reconstruction measures on river dikes.

During the overflow the following requirements have to be complied by the revetments.

- No breakup or erosion of single components has to take place.
- The revetment must not peel off the supporting structure.
- No slipping in a flat sliding joint.

The first experiments will be carried out with a combination of three different geosynthetics (Figure 6).

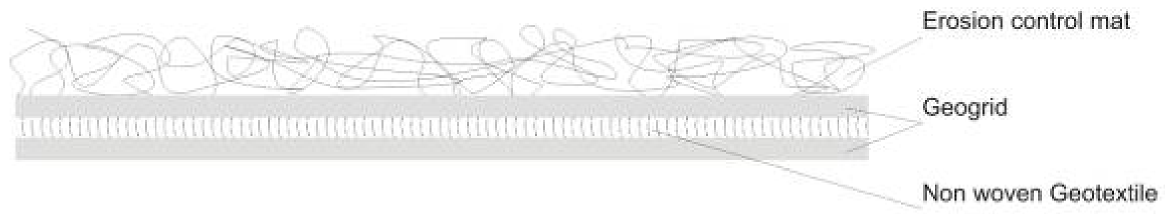

Figure 6. Architecture of the combination of geosynthetic

Each of the geosynthetics has a different function:

- **Erosion control mat** of UV-stabilized labyrinthine extruded monofilament polymer core. This material keeps the rooted topsoil together and avoids surface erosion. Usually these mats were applied to protect escarpments against erosion by wind and precipitation.
- **Geogrid** is primarily used to armor escapements.
- In between two layers of geogrid a **non woven geotextile** functions as a filter layer. This filter has high water permeability and avoids erosion and scouring by dividing different layers of soil or the soil from overflowing water.

For our tests, we take a composit of a geogrid and the geotextile.

The bracing of the geogrids diverts the stress caused by the water to the ground. Therefore the grids are fixed on the dike crest and attached extensively by pegs. Erosion control mats are attached to the geogrids and keep the rooted topsoil together. The more root penetration there is between the erosion control mats, composite and ground beneath, the better the resistance against erosion will be. Roots shall function as an additional armoring. For small weir heads we do not regard the vegetated soil as a sacrificial layer but as a part of the erosion control. It should resist overflow but is not considered in our calculations (generally it is difficult to calculate the resistance of natural materials, because their properties depend on numerous influences like the special soil structure, the rainfall or drought period etc.).

If the top soil is already eroded, the non-woven geotextile is supposed to avoid the erosion of the supporting structure (“cut down”). Our investigations will comprise a covered and rooted erosion control mat and, as worst-case scenario, an uncovered one. Thus, the overflow after the top soil and the sward have already been eroded will be simulated as well.

IV. CURRENT POSITION

The start of the full size experiment was initially planned for autumn 2007 but had to be delayed due to various problems during the preparations (March 2008). The construction of the experimental area and the set-up of the pump took longer than expected.
Since the end of April the pump is assembled. The installation of the experimental set-up has been started and it is planned to carry out the first tests in August 2008.

ACKNOWLEDGMENT

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