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Prevention from Dike Failure by Emergency Flood Control Measures

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Abstract. The risk of failure of a flood protection system must always be taken into account. During flooding events, appropriate interim protection systems must be at hand and ready to be deployed to support weak and overloaded structures. Usually sandbags, eventually in combination with fascines and geotextiles, are in use to defend endangered dike stretches in case of emergency. Sandbags offer highly flexible employment, however the enormous personal, material and time consuming efforts required for installation and dismantling are problematic. Therefore, more effective constructions for emergency flood control are needed. Within the research projects HWS-Mobile, DeichSCHUTZ, and DeichKADE different constructions based on the use of flexible membranes have been developed or are in development to ensure easy and effective countermeasures to secure dike stretches, which are in risk of breakage. Successful applications of the developed systems have taken place during the catastrophic flood event at the river Elbe in Northern Germany in 2013.

1 Introduction

Natural hazards have become natural disasters since people have been settling in flood areas. During the past decades an increasing population density and concentration of assets in low lying coastal and river areas have resulted in an increasing need for protection against floods. Therefore, the demand for technical measures for flood control is growing. However, technical structures can never provide an overall but only a limited protection against inundation. A problem that not least has been called about by restricted financial budgets. Therefore, the degree of safety depends on the cost-benefit assessment of the measure.

The possibility that a flood protection system can fail must always be taken into account. In such an emergency, appropriate interim protection systems must be at hand and ready to be deployed to support weak and overloaded structures.

In the research project HWS-Mobile, funded by the German Federal Ministry of Economics and Technology, different prototypes of water-filled tube systems for emergency flood control were developed and tested in situ as well as on test sites. After the project HWS-Mobile was completed, the water-filled tube constructions were tested and certified by the German Technical Inspection Agency TÜV Nord for deployment in emergency flood control. These innovative systems offer the following advantages:

- Low consumption of resources
- Rapid deployment
- Only few personnel required
- Deployable on different undergrounds without the need for any intrusive/destructive installations

The structures are non-stationary water-filled tube systems made of reinforced plastic membranes. They can be used for strengthening an endangered dike line during long lasting high water levels.

In the following, the construction, function and deployment of the marketable water-filled tube systems for dike strengthening, FLUTSCHUTZ Impoundment and FLUTSCHUTZ Load Filter, are described. Additionally, information is given on the ongoing research projects DeichSCHUTZ and DeichKADE dealing also with improvements in emergency flood control at endangered dike stretches.

2 Conventional dike protection systems

To secure dike sections that are at risk of breakage, structures made entirely of sandbags or sandbags in combination with fascines (cylindrical bundle of brushwood or similar material) or geotextiles are commonly used. The sandbags can be deployed either on the waterside or, most commonly, on the crest or on the landside dike slope. The latter conventional protection systems are described in the following.

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2.1 Protection against overtopping

Overflowing water at a dike destroys the inner dike face and dike base within a very short time and consequently the dike breaches. In case flood water levels are expected that will exceed the crest of a dike, the structure can only be secured by heightening the dike. Conventionally, this is done by sandbags packed trapezoidal onto the dike crest (Figure 1).

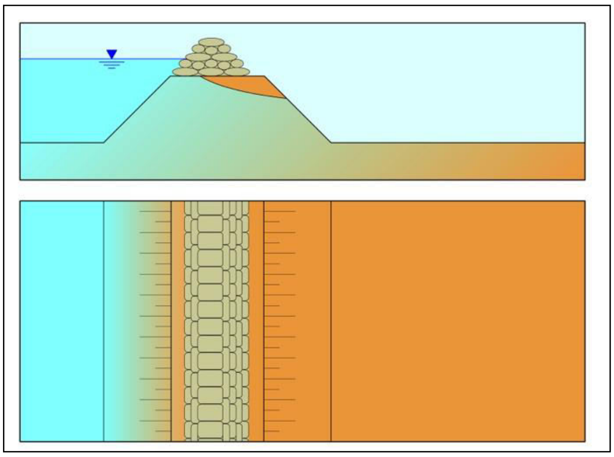

Figure 1. Dike crest heightening by sandbags

By heightening a dike crest, the safety against overtopping increases but the overall stability of the dike decreases due to higher loads and higher hydraulic gradients. Therefore, the dike heightening must not exceed 50 cm and must be installed at the waterside of the dike crest.

The width of a dam made of sandbags is approximately twice the height of the dam. For a dam 50 cm high, 100 cm wide and 1 km long approximately 35,000 sandbags are needed corresponding to 70 truckloads of filled sandbags. Neglecting the efforts for transporting the sandbags to the endangered dike section 165 helpers are needed over 8 hours (1,320 working hours) to fill, load and pack the sandbags for a 0.5 m high and 1 km long dam (calculation based on [1]).

2.2 Protection against increased local seepage

Increased local seepage in the lower regions of the landside slope must be stopped or at least hampered to prevent piping. For this, a sandbag impoundment is built around the leakage in which the water or water / sediment mixture is collected. The resulting hydraulic counter pressure reduces or prevents further seepage.

If seepage occurs around the toe of the landside slope with a low grade or behind the dike, impoundments are built as a ring dike (Figure 2). U-shaped impoundments are built around spills further up the landside slope or on landside slopes with steep gradients (Figure 3). In general it must be made sure that the majority of sandbags are placed on the toe and at the lower landside slope to impose a higher load to counteract ground failure and breaching of the slope.

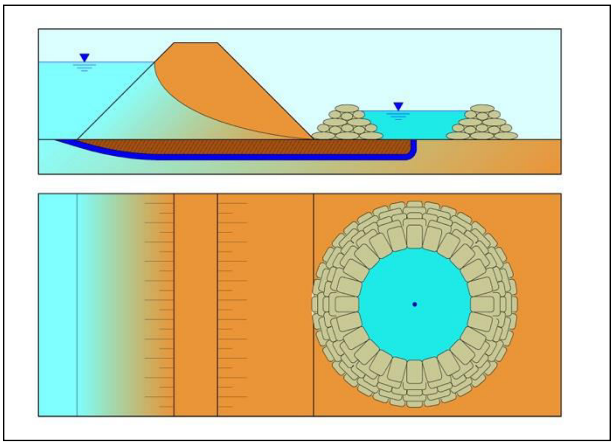

Figure 2. Ring shaped sandbag impoundment around the seepage area near the toe

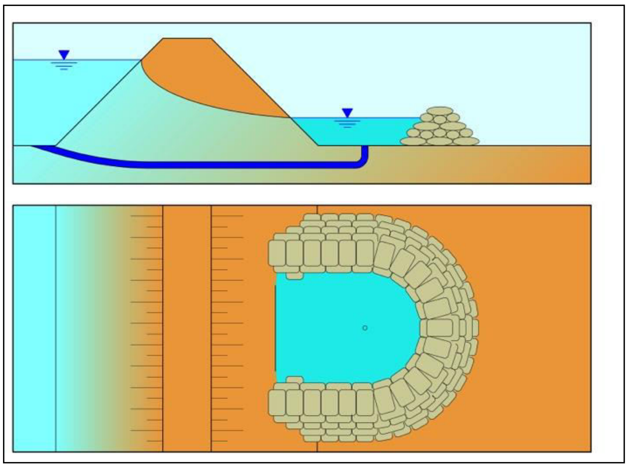

Figure 3. U-shaped sandbag impoundment around the seepage area in the lower regions of the slope

The height of the impoundment depends on the effective hydraulic gradient. The hydraulic counter load imposed by the impoundment is a function of its height. Therefore, it has to be built to a height to accommodate the water level at which seepage is blocked or at least reduced to a level at which piping no longer poses a threat.

Impoundments made from sandbags have a trapezoid cross-section. Depending on the height, the base is made of three or more sandbags placed lengthwise. On top of this, criss-cross layers are placed to create a watertight bond, in which membranes can be integrated to improve imperviousness. Typically, about 800 to 1,000 sandbags are needed to build an impoundment with a height of 80 cm [2].

When building an impoundment it has to be taken into account that by blocking the seepage in the dike, the seepage line will rise. This may cause leakages in the vicinity of the impoundment that will also need to be secured.

2.3 Protection against increased laminar seepage

Extensive laminar seepage occurs especially on dikes with a narrow crest and a steep landside slope and when prolonged high water levels have caused the seepage line in the dike to rise. Although minor seepages can generally be accepted, high flow velocities through the dike cause internal erosion leading to subsidence and slumping or slides of the landside slope and ultimately piping.

When applying measures to prevent dike failure it has to be made sure not to increase buoyancy of the dike and to ensure that seepage water is allowed to escape. Filters with an imposed load ensure sufficient drainage and provide support to stabilize a sliding landside slope.

If sandbags are used as load, a permeable grid of crossed rods or brushwood (e.g. fascines) or drainage mats must be laid out to guarantee sufficient permeability of the filter layer. This grid is placed, commencing at the toe and then slope upwards, followed by placing the sandbags in the same order (Figure 4). A sandbag load of three layers with a layer thickness of 0.3 m requires about 24 to 30 sandbags per square meter [2].

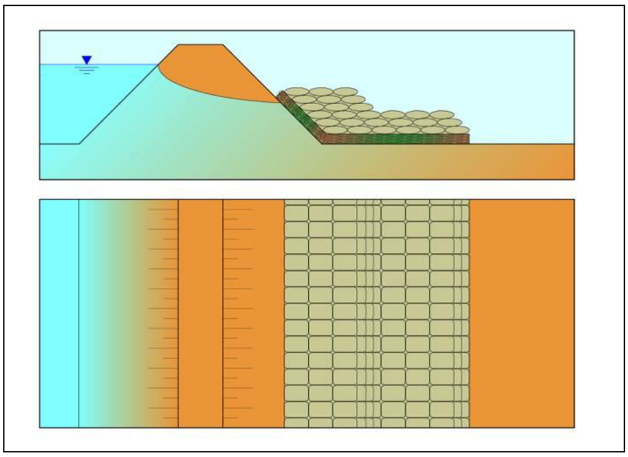

Figure 4. Supporting the landside dike slope with a permeable layer loaded with sandbags

Impermeable membranes or sheeting must not be used on the landside slope, as these block seepage flow and prevent water draining from the dike, leading to a rise of the seepage line and the dike becoming waterlogged.

If there is a lack of suitable material for building the filter layer, the supporting sandbag load must be intermitted every 2 meters by a gap of 0.2 m [3] (Figure 5).

Dikes can also be ballasted with a permeable layer of bulk material, such as gravel or alike. This method is suitable for reinforcing longer dike stretches, if appropriate material, transport, and equipment for placing the material are available. Layers of solid bulk material have to be filter-stable and, if graded, have to be stratified from fine to coarse material. This layer is built up, beginning inland of the toe slope upwards to prevent hydraulic failure in the lower region of the landside slope.

However, owing to the stress and vibration caused by heavy equipment required for transporting and placing bulk material on waterlogged dikes, this method is risky, if not impossible. It could additionally weaken, damage or even destroy the dike, dike defence paths and the adjoining hinterland or cause vehicles to sink into the ground and get stuck.

Another method is a combination of sandbag and permeable bulk material, in which sandbags are placed as cross-ledgers supplemented by an extensive layer of gravel.

The above methods are also suitable for securing dikes that have begun sliding, always taking into account that transportation and placement of material onto the slope should not be carried out prior to reinforcing the dike toe.

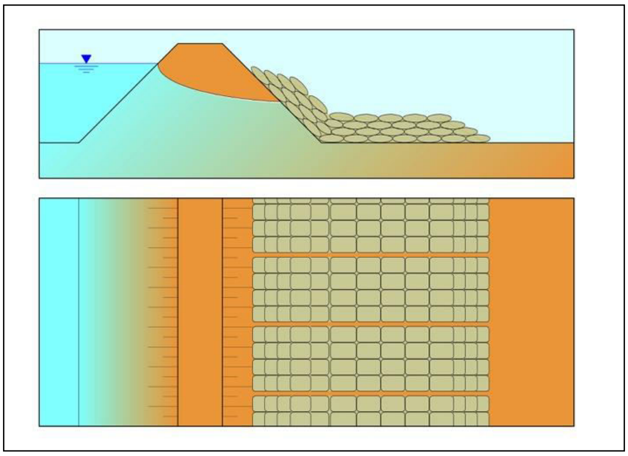

Figure 5. Supporting the landside dike slope with sandbag batches regularly intermitted by drainage gaps

3 Development of innovative dike protection systems

Innovative dike protection systems made of flexible, water-filled membranes have been developed within the research project HWS-Mobile for reinforcing landside dike slopes. They can be used around locally concentrated seepages or embankments in imminent danger of hydraulic failure. The traditional approach by building impoundments or load filter layers with sandbags and fascines can be replaced by tube structures. Testing and certification was done in situ on natural waters and on test dikes belonging to the Hamburg Authority for Highways, Bridges and Water (LSBG) and at the College of the German Federal Agency for Technical Relief in Hoya (THW).

Currently, two research projects are ongoing dealing with the development of heightening systems for dikes made of flexible water-filled membranes (project DeichKADE) as well as protection sheets for the water-side dike slope to decrease the saturation height in the dike body (project DeichSCHUTZ).

In the following, the results of the completed research project HWS-Mobile as well as preliminary results of the ongoing projects are shown.

3.1 FLUTSCHUTZ Impoundment

The FLUTSCHUTZ Impoundment is a water-filled construction for emergency dike defence. Its purpose is to rapidly reduce and confine local seepages on the landward dike slope.

For developing the FLUTSCHUTZ Impoundment, material and construction tests were carried out on an even surface and on different test dikes.

The FLUTSCHUTZ Impoundment is designed for a maximal impoundment depth of 0.90 m, which compares to the conventional THW sandbag impoundment [2]. The FLUTSCHUTZ Impoundment can be deployed by two people within 15 minutes [4]. It replaces about 1,000 sandbags that would be required for a conventional impoundment of the same size. In contrast, for the deployment of a conventional impoundment 20 helpers are needed to fill the sandbags and 7 helpers to place the sandbags at the site, both over a period of 1 hour. Additional time, helpers and equipment are required for the transport of the filling material and the filled sandbags.

The FLUTSCHUTZ Impoundment was tested and certified for flood defence by the German Technical Inspection Agency TUV [4] (Figure 7).

Figure 6. Impoundment prototype on the LSBG test dike

Figure 7. TUV certification test of FLUTSCHUTZ Impoundment on the test dike of the College of the German Federal Agency for Technical Relief THW in Hoya

3.2 FLUTSCHUTZ Load Filter

The FLUTSCHUTZ Load Filter is a water-filled load filter for emergency dike protection during continued high water periods. Deployed on the landward slope and toe it stabilises the dike sections, in which extensive seepages have arisen, against hydraulic failure or from breaching.

For developing the FLUTSCHUTZ Load Filter, material and construction tests were carried out in Grunendeich on the tidal River Elbe (Figure 8), at the Mohnetal Dam (Figure 9) and on the test dike belonging to the College of the German Federal Agency for Technical Relief in Hoya (Figure 10).

Figure 8. Load Filter prototype during a test in Grunendeich at the tidal River Elbe north of Hamburg

Figure 9. Load Filter prototype during a test at the Mohnetal Dam near Soest

Figure 10. TUV certification test of FLUTSCHUTZ Load Filter on the test dike of the College of the German Federal Agency for Technical Relief in Hoya

Simple handling makes the FLUTSCHUTZ Load Filter an alternative to the conventional sandbag-type load filters with fascines, currently used by the THW, fire brigades and other relief organisations. A 7.00 m x 3.50 m x 0.60 m FLUTSCHUTZ Load Filter element replaces about 600 sandbags required for building a load filter of equivalent size. It takes two people about 20 minutes to deploy a FLUTSCHUTZ Load Filter element [5]. In contrast, for the deployment of a conventional impoundment 13 helpers are needed to fill the sandbags and 5 helpers to place the sandbags at the site, both over a period of 1 hour. Additional time, helpers and equipment are required for the transport of the filling material and of the filled sandbags.

The FLUTSCHUTZ Load Filter was tested and certified for flood defence by the German Technical Inspection Agency TUV [5].

3.3 Dike heightening system DeichKADE

Aim of the ongoing research project DeichKADE is the development of mobile, without additional anchorage fixable and water-fillable constructions made of flexible membranes to heighten dikes during flood events in case overflowing is anticipated. The construction must offer a narrow footprint to enable the use also on old dikes with dike crest widths of only 2 m, she must offer a heightening of additional water levels of 0,5 m (see chapter 2.1) also on uneven dike crests and she must be stable also over longer time spans of several days or a week without significant maintenance requirements.

In Figure 11 and 12 the production facilities of the research partners and manufacturers OPTIMAL and Karsten Daedler are shown. Different prototypes of the system DeichKADE, the series spring and summer 2015 as well as spring 2016, are shown in Figure 13, 14 and 15. It is expected to conclude the prototype development including TUV-certification for the use of the construction in flood defence by spring 2017.

Figure 11. Construction of prototypes – production facilities of the partner OPTIMAL Planen- und Umwelttechnik, Menden

Figure 12. Construction of prototypes – production facilities of the partner Karsten Daedler, Trittau

Figure 13. Testing of the DeichKADE prototype Spring 2015 in the test container of the Partner Karsten Daedler, Trittau

Figure 14. DeichKADE prototype summer 2015

Figure 15. DeichKADE prototype spring 2016

3.4 Dike strengthening system DeichSCHUTZ

Aim of the ongoing research project DeichSCHUTZ is the development of a stabilising system for the outer dike embankment. The deployment of protection sheets at the water-side dike slope during a flood event shall lead to a decrease of the saturation height in the dike resulting in a stabilisation of the dike body. Currently, laboratory tests (Figure 16) are executed to get a deeper understanding of the processes of saturation and desaturation of soils in a dam construction giving indications for the construction of a large-scale test dike and the development of the protection sheets itself.

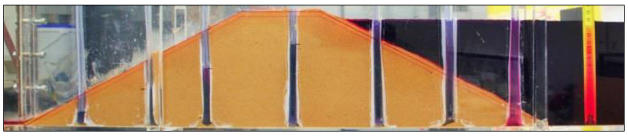

Figure 16. Laboratory tests concerning the saturation and desaturation of soils in a dam construction

In spring 2016, the large-scale test dike will be built at the College of the German Federal Agency for Technical Relief in Hoya. There, the prototype development of the protection system DeichSCHUTZ will be executed starting in summer 2016. The dimensions of the test facility are 30 m length and 25 m width with a 3 m high dike construction (Figure 17).

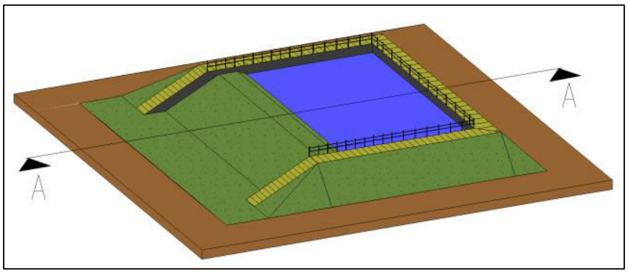

Figure 17. Layout of the planned large-scale test dike at the College of the German Federal Agency for Technical Relief in Hoya

4 Deployment of the FLUTSCHUTZ systems

In May and June 2013 heavy rains struck Central Europe leading to extreme high water levels and severe flooding in eight German federal states. It caused a high expenditure of material and manpower to protect dikes that were acutely threatened (Figure 18).

Figure 18. Construction of a load filter with sandbags to secure the landward slope of the Elbe Dike at Hitzacker in June 2013

During the 2013 flooding event, dike sections with locally concentrated seepages were successfully protected against inner erosion with FLUTSCHUTZ Impoundments (Figure 19). Curious onlookers followed the easy deployment of the structures by the German Federal Agency for Technical Relief THW Group Hamburg-Nord (Figure 20).

Figure 19. THW Group Hamburg-Nord deploying a FLUTSCHUTZ Impoundment on the Elde Dike at Domitz during the Elbe high water in June 2013

Figure 20. Curious onlookers during the deployment of a FLUTSCHUTZ Impoundment on the Elde Dike at Domitz

Also during the flooding at the river Elbe in 2013 the assembly, disassembly and function of the FLUTSCHUTZ Load Filter was demonstrated by the German Federal Agency for Technical Relief THW (Figure 21).

Figure 21. Demonstrating deployment, dismantling and operation of the FLUTSCHUTZ Load Filter by THW Group Hamburg-Altona during Elbe flood in June 2013

5 Conclusions and Outlook

The research project HWS-Mobile resulted after an intensive development and testing phase of several years in the creation of reliable and simply to operate dike protection systems FLUTSCHUTZ Impoundment and FLUTSCHUTZ Load Filter. The systems are able to replace sandbag systems without any restrictions in functionality and significant improvements in handling. Only a fraction of time, material and helpers are required for installation and dismantling of the newly developed construction offering the same or, considering the restricted available early warning time, an improved safety level. As a consequence of their successful application during the severe Elbe flooding in 2013, the systems are included in the training courses for flood agents at the College of the German Federal Agency for Technical Relief in Hoya. The systems FLUTSCHUTZ Impoundment and FLUTSCHUTZ Load Filter are on the market since 2013.

Based on the positive experiences made in the research project HWS-Mobile follow-up projects to develop reliable and easy to handle systems for heightening dike stretches during a flooding event and to stabilize weak dike bodies by lowering the saturation degree with protection sheets at the waterside dike slope are in execution. Successful prototype development in these projects is anticipated in the year 2017.

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