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More resilient levees using geotextiles

Flood events occur regularly in Germany, with the dykes as flood protection structures taking centre stage. Due to the high water levels in conjunction with often long-lasting flood events, the stability of the dykes, which are usually built as homogeneous earth structures, was often critical, and in some cases the dykes even failed. By using geotextiles, dykes can be reinforced or secured both in the course of new construction or upgrading and immediately before or during flood events in such a way that the typical cases of failure can be prevented or at least significantly delayed. Some possible applications of geotextiles for short and long-term preventive measures are presented in this article. These are both state of the art applications and innovative applications of geotextiles in dykes.

1. Introduction

In 2023, two major flood situations occurred in Germany in which more resilient dykes could have contributed to flood protection. In October 2023, a severe storm surge in the Baltic Sea caused considerable damage, including dyke failures along some stretches of the coastline. In December 2023, prolonged, supra-regional rainfall led to the so-called "Christmas Flood 2023." During this event, which affected central and northern Germany, not only high water levels but also the extended duration of flooding created stability problems for the dykes. Typical forms of failure of dykes are caused by overflow, erosion on the water side or throughflow/underflow. These broad failure patterns are shown in abstract form in Figure 1 and can be further specified and combined as needed.

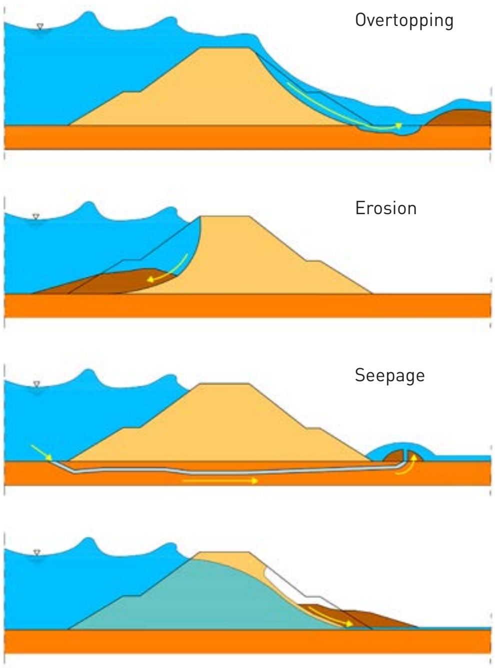

Figure 1: Typical failure modes of dykes (modified after [19])

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Dykes are governed by DIN 19712 [1], which outlines principles for their construction, renovation, maintenance, monitoring, and flood-defense operations. Within [1], geotextiles in dykes are mentioned for disaster-related flood protection, specifically for achieving filter-stable separation of drainage and supporting structures, as well as for improving overall dyke stability. In [2] and in the central DWA-M 507-1 [3], the use of geotextiles and geosynthetics is addressed in a dedicated subchapter and also referenced in numerous other sections. Both [1] and [3] explicitly exclude seawalls from their scope, but recommendations for seawalls can be found in [4]. These recommendations are far more comprehensive regarding geotextiles. Specifically, [4] C 2002 Building Materials for Coastal Protection Structures contains a detailed chapter on geosynthetics and geotextiles, stating that "engineering applications in geotechnics and hydraulic engineering are inconceivable without geosynthetics." Furthermore, [4] G 2002 Sea Dykes and Tidal Stream Dykes addresses in detail the reinforcement of dyke contact surfaces with geosynthetics.

Although geotextiles are included in the relevant standards and regulations, they are covered in varying levels of detail, and their many uses and applications are not comprehensively listed. This article therefore provides an overview of the applications already mentioned in current regulations and highlights additional ways geotextiles can be applied in and on dykes to enhance their resilience.

2. Applications of geotextiles in dykes

The applications of geotextiles in dykes can be categorized into short-term preventive measures, which are implemented immediately before or during flooding, and long-term measures, typically undertaken as part of new construction or renovation projects.

2.2 Short-term preventive measures

2.2.1 Geotextile tube mats as ballast and slope erosion protection for water and air side

Introduction

Geotextile tube mats consist of interconnected tubes laid side by side over a large area, which are hydraulically filled with sand or other suitable filling material. It is crucial to ensure filter stability with respect to the fabric. The tubes, which can vary in diameter depending on the weave, may be sewn together to form larger panels either at the factory or on site using an appropriate hand-sewing machine prior to filling. These panels can also be joined or overlapped. In a one-sided application, the tube mat should be anchored to the embankment crest. If the mat is installed in a saddle shape, its position can be secured by filling the tubes in parallel on both sides of the embankment (Fig. 2).

Figure 2: Tube mat as one-sided application on the air side of the dyke

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Benefits /Applications

By installing such a tube mat, damage to the dyke surface can be prevented on the water side, while the mat simultaneously serves as ballast on both the air and water sides. On the air side, it also acts as a surface filter, preventing erosion from within the dyke. As only a pump, water, sand, and possibly an excavator are needed for filling, a tube mat is particularly suitable for structures with limited resources and personnel. Thanks to its standard width of five meters, a tube mat enables rapid installation.

Furthermore, due to hydraulic filling, these mats can be filled from the dam crest, even underwater in the event of flooding.

2.1.2 Sand container as an emergency measure

Introduction

Geotextile sand containers often referred to as sandbags are high-strength woven or non-woven geotextile bags that can be filled with locally sourced material. With sizes of up to 5 m^3, they are much larger than standard handheld sandbags. Their permeable construction allows water to flow through, reducing the risk of hydrostatic pressure build-up while keeping the filling material contained. According to [5], geotextile sand containers can be designed to withstand wave loads and current forces, and their stability against sliding and tipping can be verified according to [6].

Benefits

The primary advantage of geotextile sand containers lies in their flexibility, which allows them to adapt to varying shapes and contours of the landscape. They are also available in different sizes (1.0 m^3 to 5.0 m^3) for a range of applications [7]. Because of their robust design, larger geotextile sand containers can withstand higher flow velocities and wave forces than smaller bags [5]. Moreover, using larger containers can secure affected sections more effectively and rapidly.

Geotextile sand containers can be filled on site with minimal equipment and expertise, making them highly versatile. Their simplicity comes from using readily available local fill materials such as sand, soil, or gravel. This approach not only lowers costs but also minimizes environmental impact by reducing the need for transported resources.

After filling, the containers can be closed on site with either a hand-sewing machine or a drawstring, enabling quick and easy deployment during emergencies. When unfilled, they are lightweight (Fig. 3), making them easy to store, transport, and install—even in remote or hard-to-reach locations.

Figure 3: Transportation and laying of large sand containers

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Applications

In emergency situations, geotextile sand containers are an essential tool for erosion control, particularly for reinforcing dykes. They offer a quick, effective means to create a surcharge and strengthen dykes against threats such as flooding, storm surges, or other environmental hazards. By strategically placing geotextile sand containers along vulnerable sections of a dyke, authorities can rapidly reinforce its structural integrity, preventing breaches and minimizing the risk of catastrophic flooding [8].

These containers also provide a means to swiftly raise the height of dykes, offering an immediate response to rapidly changing water levels during emergencies (Fig. 4). In addition, their durability and flexibility make them ideal for repairing damaged dykes by reinforcing weakened sections or filling breaches ensuring faster restoration of flood protection.

Figure 4: Temporary flood protection structure made of 1 m^3 sand containers

2.2 Long-term measures

2.2.1 Reinforcement of the dyke contact area with geotextiles

Introduction/Application

When constructing dyke structures, it is often necessary to implement structural measures to ensure stability and serviceability. In the event of stability issues, geotextile dyke base reinforcements can be used to compensate for load deficits. When designing both the dyke body and any associated structural measures, it is crucial to ensure that deformations do not compromise the dyke's functionality or its components—namely, the supporting body, seal, and drainage layer in three-zone dykes. Current design guidelines contain ambiguities and misunderstandings regarding system behavior and the relevant requirements, which necessitate further technical discussion. For example, DIN 19712 [1] requires a maximum relative elongation of 1% under permanent load for geotextile dyke base reinforcement, but the precise meanings of "relative elongation" and "permanent load" are not clearly defined. Moreover, imposing a blanket elongation limit without considering the position and type of sealing element can lead to unnecessary costs. While an elongation limit makes sense for an internal core seal, it is irrelevant for an external, slope-parallel clay seal. If the subsoil is predominantly horizontally stratified—i.e., if a settlement trough forms below the dyke body—then the slope flanks, and therefore the water-side sealing element, become compressed [9].

Where the ground is extremely soft or has low bearing capacity, additional measures may be necessary to limit settlement. In addition to replacing the soil with low bearing capacity, soil improvement with gravel columns or geotextile-coated sand columns can be used, as demonstrated in the expansion of the Airbus site in Finkenwerder, Hamburg [10].

Application example

As part of the redesign of the Emscher catchment area in Dortmund, a flood protection dyke was required in the Wischlingen district to close a gap, enabling a topographically suitable area to be used for retaining heavy rainfall runoff in the future. A notable feature of this project area is the presence of locally occurring, very thick peat layers and highly organic silts, which required special consideration regarding the stability and settlement behavior of both the dyke and its foundation.

To address these concerns, a variant study was carried out to evaluate different methods of subsoil improvement aimed at enhancing stability and accelerating the inevitable deformations. The chosen approach involved a relatively rigid geotextile-based dyke base reinforcement, providing the necessary stability during the early construction stages. This solution allowed the dyke body to be built continuously without waiting for interim consolidation periods, thus preventing disruptions to the construction process.

To ensure serviceability, the dyke was initially raised by the expected amount of settlement, reaching elevations of up to 100 cm in areas with particularly soft soils. By hydraulically connecting the dyke foundation to an additional drainage layer beneath the dyke body, the consolidation period was limited to a manageable timeframe, avoiding the need for further measures to expedite consolidation [11].

2.2.2 Erosion resistant dyke core made out of geotextile tubes

Introduction

Geosynthetic tubes—also referred to as geotextile tubes or coastal protection tubes—are flexible containers made of geotextiles originally developed for geotechnical and civil engineering applications. Available in various lengths and diameters, these tubular structures are primarily used for erosion control, coastal protection, and preserving or restoring coastlines and riverbanks. They are hydraulically filled with locally available sediments (e.g., sand), allowing excess water to drain through the geotextile while retaining the sediment (Fig. 5).

As with geotextile sand containers, the stability of geosynthetic tubes can be designed to resist wave loads and current forces in accordance with [5].

Figure 5: Geotextile tube during filling

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Benefits

Geotextile tubes offer numerous benefits for dykes and dams, increasing their effectiveness in flood protection. They reinforce these structures and enhance their stability against hydraulic forces and erosion, all while permitting seepage water to pass through and preventing internal erosion. The high-tensile geotextile shell ensures the long-term integrity of dyke systems—particularly homogeneous ones.

Compared to sandbags (see Chapter 2.1.2), geotextile tubes are more resistant to settlement due to hydraulic filling combined with a high-tensile, low-creep tube cover. This construction prevents sand particles from shifting by creating a ring force within the tube. In addition, geotextile tubes enable rapid construction and installation, which shortens response times and reduces overall project duration.

They also offer cost-efficient solutions when compared to traditional materials and methods, contributing to a more sustainable dyke infrastructure. Depending on availability of traditional fill material, using geotextile tubes in the core can significantly reduce CO_2 emissions.

Applications

Geotextile tubes are preferably used as the core of a structure, as the subsequent covering with bulk material preserves the durability of the tube shell. In principle, geotextile tubes can be integrated into any flood protection or hydraulic engineering structure. For structures that remain permanently below the water surface such as submerged breakwaters, the tubes can be installed without a cover. However, uncovered structures situated on dry land should only serve as temporary installations.

Application example

Tocopilla is a city on the Pacific coast of Chile. To safeguard its new beach from strong wave and current forces, two breakwaters were constructed (Fig. 7). Instead of rubble, the breakwaters' cores were filled with locally available sand contained in geotextile tubes for several reasons.

As water depth increases, the coastal protection tubes are stacked in up to three layers. Each layer is then covered by a final revetment made of stones weighing up to 10 tons (Fig. 6). By using locally sourced material in the breakwater core, approximately 900 tons of CO_2 emissions—and numerous transports—were saved compared to a traditional stone fill.

Figure 7 shows an aerial view of the completed beach in Tocopilla.

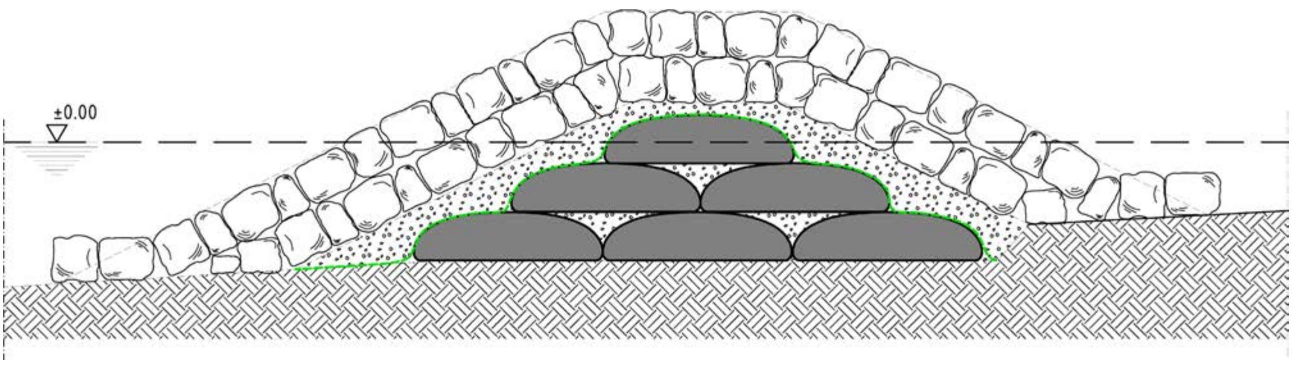

Figure 6: Cross-section of breakwater

Picture 7: Beach in Tocopilla after completion

2.2.3 Continuous tubes using machine

Introduction

Another application involves the on-site assembly and filling of tubes using a so-called "tube paver." The tube finisher (Fig. 8) is supplied with locally available soil via a hopper, typically using an excavator or similar equipment, and the soil is then conveyed into a geotextile fabric, formed into a tube by parallel screw conveyors. During this process, the material is vibrated for compaction. The tube is then automatically sealed with seam, using a sewing machine integrated into the same machine.

The tube fabric can be either synthetic or biodegradable. Depending on the application, it must have sufficiently high and permanent tensile strength to ensure the seam strength and maintain the tube's internal stability.

Figure 8: Tube paver (Dybatec)

Benefits/ Applications

The finished tube is discharged from the machine as an endless tube via a moving conveyor belt. Since the belt is mounted on a movable arm and the machine itself is equipped with a crawler chassis, the tube can be laid parallel to or alongside a flood protection element as ballast on the embankment or used to increase the height of an embankment (see Chapter 2.2.5). This versatility makes the tube finisher suitable for short-term preventive measures as well (see Chapter 2.1). The crown seam ensures that the encapsulated material remains permanently contained, preventing any discharge due to prolonged overflow or tube movement.

Endless tubes with diameters of around 0.50 m can serve as structural elements in disaster response, earthworks, hydraulic engineering, and dyke and embankment construction. In all these applications, the tubes act as a supportive skeleton, providing the structures with flexible stabilization.

Figure 9: Tube from a tube paver

Developed in collaboration with TU Dresden and the Saxon Textile Research Institute Chemnitz, this process is characterized by a high degree of innovation and wide-ranging applications. With a tube diameter of approximately 50 cm and an output of about 120 m/h, large sections can be rapidly secured.

Building on this technology, an experimental study is currently underway at the Center for Coastal Engineering at TU Braunschweig to investigate how coastal protection dunes can be reinforced and stabilized using this method.

2.2.4 Sealing with geosynthetic clay liner

Sealing a body of water, reservoir, or flood protection structure with a geosynthetic clay liner (GCL) is now considered standard practice and will be covered briefly in this article using an illustrative example. A GCL typically consists of a needled or stitched composite generally a woven carrier layer and a non-woven cover layer filled with bentonite granules or powder, it should be placed on a pre-graded substrate. To prevent uncontrolled swelling of the mat, a ballast layer must be installed immediately afterward. Further details and design guidelines can be found in [12] and [13], among other sources.

Application example

The 14.7 km long Rench flood channel in Baden-Württemberg carries floodwater from the upper reaches of the River Rench. Soil mechanics and dyke construction reports showed that the dykes built between 1936 and 1968 no longer met current engineering standards and could not guarantee the necessary stability during flood events. The most significant deficiency was insufficient freeboard between the maximum allowable dam height and the dyke crest in many sections. To prevent overtopping, these areas had to be raised by around 1 m, and the trapezoidal profile had to be reinforced. The flood channel is designed to accommodate a discharge of 230 m^3/s.

To address these issues, NaBento® RL-N+ geosynthetic clay liners (GCL) were installed across the entire water-side embankment surface. Figure 10 shows the GCL (in black) on the profiled embankment, along with the applied backfill; installation was carried out in the rolling direction from the base to the crest using the traverse system also depicted. The sand-rough surface texture of the GCL provided the necessary stability in steeper embankment sections, both during construction and in the final state. Thanks to this solution, the renovated, raised embankment body now has a durable, functional seal and achieves a significantly reduced construction thickness as compared to a conventional clay seal.

Figure 10: GTD on the Renchflut canal in the installed state

2.2.5 Raising the dyke height with geotextile tubes

This chapter focuses specifically on the use of geotextile tubes to raise a hydraulic engineering structure.
For foundational information on geotextile tubes, please refer to Chapter 2.2.2.

Benefits/ Applications

As flood events continue to intensify, there has been ongoing discussion about raising the crests of existing flood protection structures. Traditionally, this is done by adding material to the existing crest. However, because dams and dykes often have low slope gradients, raising them while maintaining those gradients generally requires increasing the contact or footprint area. In addition to the logistical challenges posed by buildings located close to the embankment base and limited land availability, this conventional approach also involves significantly higher material usage not just for the crest but also along the embankment slopes.

Geotextile tubes mentioned in Chapter 2.2.2 present a viable solution to these challenges. Their geotextile casing permanently retains the fill material, and they have a relatively small footprint, making it possible to install them directly on the existing crest. Depending on project requirements, the tube material can be protected, for instance, by placing a sacrificial material over it to ensure long-term durability of the tubes.

Besides the geotextile tubes described in Chapter 2.2.2, tubes produced with the machinery outlined in Chapter 2.2.3 can also be employed to raise the crest. The decision on which system is most suitable should be made on a project-specific basis.

2.2.6 Erosion protection using 3D grids

Introduction and Benefits

Erosion protection grids primarily consist of a three-dimensional mesh that enhances soil retention and allows the roots of overlying vegetation to anchor themselves. High tensile strength simplifies the installation process, even on extended and steep slopes. Special coatings provide robust UV resistance and safeguard against mechanical damage, ensuring a long service life—particularly in more demanding erosion control applications.

Figure 11: Erosion protection grid (Fortrac® 3D)

Erosion control grid with ingrown turf, taken from [14]

Applications

The vast majority of flood protection elements are earthworks that lack highly resilient revetments above the mean water line. To protect these unfortified embankments from erosion damage during flooding, erosion protection grids can be installed to enhance resilience. Typically, these grids are placed on a stable, level surface free of protrusions. It is also crucial that the substrate be suitable for vegetation, as plant roots play a key role in protecting the entire system from erosion. Accordingly, selecting an appropriate seed mix during the planning stage is essential. Numerous scientific studies have confirmed the effectiveness of erosion protection grids under both wave and current loads.

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The hydraulic load capacity was verified according to ASTM D 6460 [15]. In a separate investigation [16], tests were conducted in three large-scale flumes equipped with Fortrac® 3D-30 as erosion protection, placed over a straw mat on top of a 30.5 cm layer of sandy, silty clay. Each flume represented a different vegetation condition, ranging from bare soil (no vegetation) in flume 1 to one-year-old growth in flume 3 (see Table 1). For every vegetation scenario (unvegetated, six-week growth, one-year growth), at least four consecutive runs were performed. Each run lasted 30 minutes for unvegetated conditions or one hour for vegetated conditions, with the flow rate increasing in each run until a specified shear stress was reached. This limit corresponded to an average soil loss of 1.3 cm across the entire channel bottom and was evaluated after each run.

Key results—such as permissible shear stress and maximum flow velocity—are summarized in Table 1.

	Ungreened	**Greened, Six-week growth**	**Greened, One-year growth**
Growth period [Weeks]	0	6	64
τ_{limit} **[N/m²]**	110	225	630
υ_{limit} **[m/s]**	2.8	3.5*	7.3*

Table 1: Summary of the results of the large-scale test with Fortrac® 3D-30 and sandy, silty clay

Application example

The Tagliamento is an Italian river that flows largely unregulated in its upper reaches but has been canalized further downstream to guide it safely through several towns before entering the Adriatic Sea. In 1965 and 1966, the region experienced severe floods, including dyke breaches in the village of Latisana, which led to significant destruction. Over time, the dykes in this area were reinforced and protected against erosion. In Latisanotta, a suburb of Latisana, Fortrac 3D was installed on the air side of the dyke separating the Tagliamento floodplain from the town. This erosion protection grid prevents retrogressive erosion in the event of dyke crest overflow and was subsequently covered with topsoil and vegetation (Fig. 12).

Figure 12: Erosion protection grid during installation;

After greening

In 2023, another major flood struck the region, with water levels comparable to those recorded in 1965 and 1966. Thanks to the installed erosion protection on the air side of the dyke, no breach occurred, averting the threat of flooding in Latisanotta.

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2.2.7 Introduction should be in next line and not with main heading

Introduction

Concrete mats are an innovative erosion control solution that use two layers of permeable geotextiles as formwork, connected either by spacers or predefined filter points. When highly flowable concrete is poured into this textile formwork, it forms adaptable structures suitable for various applications, such as erosion protection on spillways and bank reinforcement [17]. If a concrete mat with a constant cross-section is used without filter points, it can also serve as a sealing element.

The thickness of a concrete mat can be adjusted to accommodate site-specific conditions. According to [17], the necessary thickness and type of concrete mat can be designed to withstand flow and wave loads by accounting for various local factors, such as slope and subsoil permeability. In some cases, however, application-specific investigations are required, as illustrated by [18].

Benefits

Concrete mats form a cohesive structure that offers numerous technical advantages, including the flexibility to create project-specific shapes and configurations, enhanced structural integrity, controlled material placement, uniform concrete thickness, and high resistance to hydraulic forces. Because each section acts as a single unit, there is no need to demonstrate pull-out safety for individual elements (as would be required in a traditional block revetment), allowing concrete mat revetments to be significantly thinner.

Their relatively lightweight, flexible nature enables easy adaptation to various terrains, environmental conditions, and underwater installations, and also allows vegetation to establish and blend with the surrounding landscape. In addition, concrete mat revetments are cost-effective and environmentally friendly, requiring less material and labor than traditional construction methods making them a sustainable choice for many projects.

Despite an average thickness of only 10–20 cm, concrete mats installed in dyke overflow sections can easily withstand flow velocities of 10 m/s or more [18]. This performance is partly due to their cohesive design, which distinguishes them from conventional rock solutions.

Applications

Due to the variety of available types, concrete mats can be used in a range of applications. For flood protection structures, they provide an effective way to protect the overflow sections of a dyke, which can subsequently be vegetated to blend seamlessly into the landscape. In particular, a concrete mat featuring large filter points arranged on a 30 cm × 30 cm grid (Incomat® Crib 10.200 by HUESKER Synthetic GmbH) was tested at the Vienna University of Technology for its performance in the overflow area of a dyke [18].

In this experiment, a concrete mat was installed in the overflow channel from the dyke crest, down the air-side embankment, and beyond the end of the stilling basin and then subjected to a long-term load under various specific flow conditions. The maximum flow rate reached 2.0 $m^3/(s \times m)$ over 17 hours, corresponding to a peak flow velocity of 10.5 m/s. Throughout the test, the concrete mat remained undamaged; the laboratory setup did not allow for further increases in flow rate or velocity.

Application example

In order to protect the municipality of Oberaich, near Bruck an der Mur (Styria, Austria), against the devastating consequences of local heavy rainfall events, various protective structures were built in the catchment area of the Picheldorfer Bach. The plans included the construction of a rainwater retention basin with flood relief via an embrasure into the adjacent St. Dionysen power plant canal. The affected section of the existing dam is exposed to considerable hydraulic loads in the event of overflow, which could result in severe erosion and ultimately a dam failure.

To prevent such overflow-related damage from compromising the dam's stability, the spillway area required an erosion-proof revetment. First, the existing crown was excavated and shaped to match the required geometry for the overflow channel. A concrete mat was then installed, followed by a humus layer seeded with vegetation, making the mat invisible from the surface (Fig. 13). In an overflow situation, the vegetation can be washed away or removed, with the concrete mat underneath assuming the role of erosion protection. At the same time, the mat's water permeability helps promote healthy plant growth soon after installation.

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Figure 13: Concrete mattress after installation; after greening

3 Conclusions

This article demonstrates that the broad spectrum of geotextile-based solutions can be used both as short-term preventive measures and as long-term flood protection strategies. Several of the presented applications are already considered state-of-the-art, as evidenced by the numerous examples of their practical implementation. Other measures described have a more innovative character, which accounts for the relatively few existing application cases. The most forward-thinking approaches—those without any current references—require willingness from planners, authorities, and contractors to explore new methods, along with an innovative mindset.

Despite potentially higher construction-phase costs, these solutions offer clear advantages by reducing vulnerability and providing a higher degree of structural protection. Overall, each of the measures discussed shares the common benefit of increasing the resilience of flood protection structures, thereby reducing their susceptibility to known failure patterns.

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HUESKER Synthetic is certified according to ISO 9001, ISO 14001 and ISO 50001.