TWO RESEARCH DIKES MADE OF FINE-GRAINED ORGANIC DREDGED MATERIALS

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Abstract. In the DredgDikes project two research dikes with the use of fine-grained dredged materials have been realised. The first construction is a research dike facility on the Hanseatic City of Rostock's containment area, which has been designed to test different dredged materials with considerable fine fraction and organic content to be used as dike cover material. Therefore, ten different dike cross-sections have been realised in two parallel dikes, one of which is instrumented for seepage control while the other one has been used to test the land side slope regarding its erosion resistance with respect to crest overflowing. During the construction in 2011 and 2012 a variety of issues concerning the installation of the materials, their characterisation and their general stability have been investigated. The second construction is a pilot dike, built in winter 2013/14 at the Körkwitzer Bach, a small river 30 km east of Rostock. Again, fine-grained, organic dredged material was used for the dike cover. The installation and greening methods applied follow the knowledge gained in the construction of the research dike. The pilot dike will be instrumented for a long-term monitoring programme which will be followed beyond the project lifetime. Both constructions generally show a good potential for the fine-grained dredged materials to be used in dike construction. Some issues such as dessication cracking are still subject to investigations.

Keywords: Dredged materials, research dike, dike construction, pilot dike, full scale experiments, flood protection, dike reconstruction

1. Introduction

Large amounts of sediments are removed every year from water bodies in maintenance and environmental dredging projects. In the eastern Baltic Sea large harbour projects will involve considerable dredging (ECODUMP 2014). The major amount of these dredged materials is relocated within the water bodies (Netzband et al. 1998; HELCOM 2011), however, if the amount of fines in the sediment would cause turbidity at the placing area or contaminations are involved, the materials have to be taken ashore which makes them waste materials after European regulations (Neumann and Henneberg 2014). Still, the materials are a valuable resource for agricultural use, landscaping or even as construction materials, particularly when they are not contaminated. Dredged materials that contain considerable amounts of fines and organic substance are usually dewatered and ripened before re-use. Experience shows, that some of the materials are well suited for the recultivation layers of landfill cappings, where high erosion resistance and extreme water retention capacities could be observed (Morscheck et al. 2014).

This resulted in the proposal to use this kind of dredged material as coastal dike cover material. The usual dike cover materials such as marsh clay (North Sea) and glacial marl (Baltic Sea) are becoming short and they have to be mined, usually in environmentally sensitive areas, while the dredged materials are readily available and need to be used beneficially. This is even a demand of the European Commission through the European Waste Framework Directive (Neumann and Henneberg 2014). Therefore, the cooperation project DredgDikes -part-financed by the European Union's *South Baltic Programme*- was initiated by the *Chair of Geotechnics and Coastal Engineering* at Rostock University (UR) and the *Department of Geotechnics, Geology and Maritime Engineering* at Gdansk University of Technology (GUT). Five partners and 16 associated organisations from Poland, Germany, Denmark, Latvia and Lithuania are involved in the project. The main aim of the project is to get different solutions for dredged materials application in dike construction implemented and therefore a recommendations handbook will be developed as final result. Information about the project can be found on *www.dredgdikes.eu*.

The German partner institutions are investigating ripened fine-grained organic dredged materials in combination with geosynthetics solutions, while in Poland GUT is investigating how different ashes and rather sandy dredged materials can be mixed to gain valuable dike construction materials for both the dike core and dike cover layers (Sikora and Ossowski 2013). In the frame of the project DredgDikes three research dikes have been built. The Gdansk research dike made of an ash-sand composite is not issue of this paper. Focus is rather set on the constructions that have been built near Rostock, involving the application of fine-grained dredged materials: A test dike constructed on a containment facility of the Hanseatic City of Rostock which is used to simulate infiltration, seepage and overtopping and a pilot dike construction at the *Körkwitzer Bach*, 30 km east of Rostock, which has an actual flood protection function.

2. The DredgDikes Full-Scale Research Dike in Rostock-Markgrafenheide

2.1 Planning and Design

The large-scale research dike in Rostock consists of two parallel dikes (west and east) which are connected with earth dams to form a three-polder system (Fig. 1). The polders can be filled with water separately for hydraulic loading. There are ten different dike cross-sections, all separated by mineral sealing material to prevent seepage water to spread between the sections. Most of the sections have been realised twice, on the eastern and the western dike respectively.

The water level inside the polders can be regulated so that water flows over the crest-areas particularly lowered to realise overflow on defined parts of the slopes. The base of the construction is sealed by a geosynthetic clay liner for a defined hydraulic boundary condition. Five different dredged materials and four different geosynthetic solutions have been installed in the German test dike.

Three general types of cross-sections were realised: The dikes of polder 1 consist of a sand core covered with a layer of fine-grained dredged material with a thickness of 1.5 m on the outer (water side) slope and 1.0 m on the inner (land side) slope and a slope inclination of 1:2. In polder 2 slopes with an inclination of 1:3 are realised. The cross-sections consist of a sand core covered with a layer of fine-grained dredged material of 1.0 m thickness. Cross-section H in polder 3 is a homogenous dike made from a dredged material with a higher sand fraction compared to those used in polders 1 and 2.

To reduce shrinkage cracking in the dike cover layer, a geosynthetic reinforcement product was considered in surface parallel layers. Since the tensile stresses at crack development are assumed to be very low compared to the tensile strength of geosynthetic materials and the friction between soil and reinforcement material needs to be high even for very small displacements, a geosynthetic erosion control grid (*Huesker Fortrac 3D*) was used. Without reinforcement large cracks were expected that may reach the sand core. With reinforcement installed, a larger number of smaller cracks were expected, not exceeding the reinforcement (Fig. 2A).

To strengthen the surface of the greened slopes against erosion from wave attack or overflowing / overtopping events, a rolled erosion control product RECP (*Colbond Enkamat*) was considered on several cross-sections (C, E, F in Fig. 1), covered by up to 5 cm of dredged material before greening. The *Fortrac* grid was also used as surface erosion control solution on one of the steep cross-sections. Without RECP considerable erosion may occur, particularly in bare or partly vegetated state, while with RECP the surface will be protected (Fig. 2B).

In the homogenous cross-sections of polder 3, innovative drainage solutions using a geosynthetic drainage composite (*Colbond Enkadrain*) shall control the phreatic line inside the dike core. Without installed drainage composite seepage water may soak the whole cross-section, coming out anywhere on the inner slope. With drainage composite, the seepage line should drop to the drainage layer and come out at a defined line along the slope or dike toe (Fig. 2C).

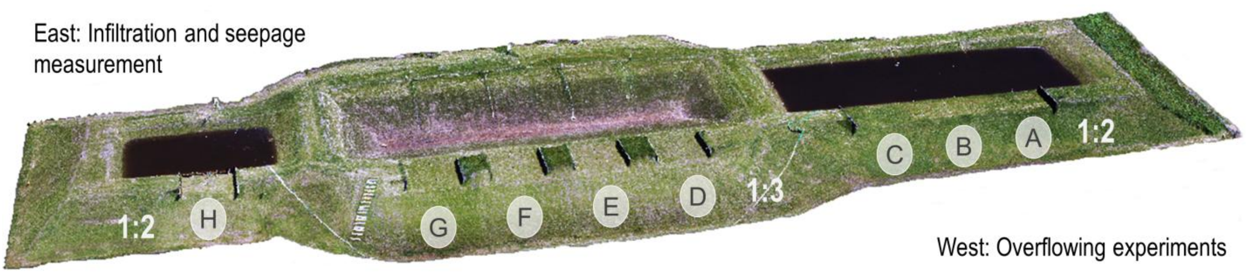

Fig. 1. Rostock research dike, west view (Cantré and Saathoff 2014).

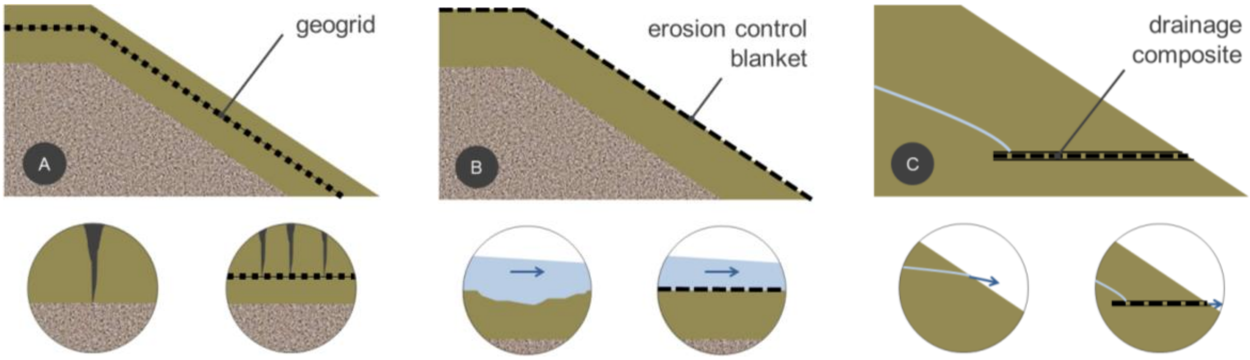

Fig. 2. Schematic cross-sections: A. Sand core & geogrid reinforced dredged material cover. Without geogrid large cracks. With geogrid more smaller cracks not exceeding the geogrid. B. Sand core & erosion protected dredged material cover. Without erosion control blanket - surface erosion due to overflowing. With erosion control no erosion is expected. C. Homogenous dike with geosynthetic drainage composite. Without composite seepage may occur on the inner slope. With composite defined drainage (Cantré and Saathoff 2013).

Table 1. Selected geotechnical properties

	M1	M2	M3
Clay [%]	25-28	22-25	15
Sand [%]	29-34	40-47	54
Water content w [%]	61-68	55-73	46
Organic matter OM [%]	10-11	9-10	6
Lime content LC [%]	9-10	8	10
c_u [kPa][1]	53-132	19-34	>120
φ [°][2]	28-30	28-31	30
c [kN/m²][2]	35-47	13-19	59
k_f [m/s]	5E-08	8E-10	5E-09
OD [g/cm³]	1.1-1.2	1.3	1.4
w_{opt} [%]	40-43	32-35	31

M1: Organic silt ripened for 5 yrs. M2: Organic silt ripened for 2 yrs. M3: Sandy silt, slightly organic.
[1]Results from vane shear tests
[2]Results from direct shear tests

2.2 Material Characterisation

In the research dike five different dredged materials have been used to build dike core, cover layer and homogenous dike sections. Three of them are ripened fine-grained and organic dredged sediments from the Warnow river delta in Rostock. They have been processed on the City of Rostock's containment facility *Radelsee*. The containment facility consists of two classification polders, long enough for the separation of different grain size classes of the dredged material: pure sand, mixed "top soil" (M3 in Table 1), and fine-grained organic materials (M1/2). After one year of dewatering the materials are usually removed from the classification polders and set up to heaps on the ripening fields. The ripening is particularly important for the fine-grained organic materials. M1 and M3 had been ripened for 6 years prior to installation, while M2 had been ripened for only 3 years when installed in the test dike while they had been ripened 5 and 2 years prior to testing respectively. In Table 1 some important soil mechanical values are given for characterization. More detailed information about the geotechnical characteristics of the dredged materials used in the project, including the comparison to other dredged materials and standard dike construction materials have been published by Große and Saathoff (2014).

2.3 Construction of the Research Dike

In spring 2012 the actual dike construction started. Due to the different slope inclinations and cross-sectional designs the construction technology was adjusted several times. A detailed description of the varied installation technologies and their performance is provided in Cantre and Saathoff (2013).

Three different compaction methods were used in the installation tests: a sheep's foot roller compactor with vibrator (12.5 t), a standard roller compactor with vibrator (12.5 t), and a standard caterpillar (13.0 t). The evaluation of all compaction data gathered showed only small differences between the compaction results (Table 2 and Fig. 3).

Initially it was supposed that the compaction results after caterpillar compaction only would be considerably lower than those after installation with roller compactors. Data evaluation shows a 6% lower degree of compaction (DOC, mean values) for M1 when compacting with the caterpillar only, which is significant. For M2 a 2.5% lower DOC was observed, which is not significant with respect to the data population.

As a result the compaction with a caterpillar only was chosen for installation efficiency due to the small

Table 2. Results of the DOC analysis from the test dike

	Roller	**Caterpillar**
M1		
Number of values	23	27
Mean value	78.6%	72.4%
Standard deviation	6.33%	4.61%
M2		
Number of values	28	27
Mean value	84.2%	81.7%
Standard deviation	6.35%	8.27%

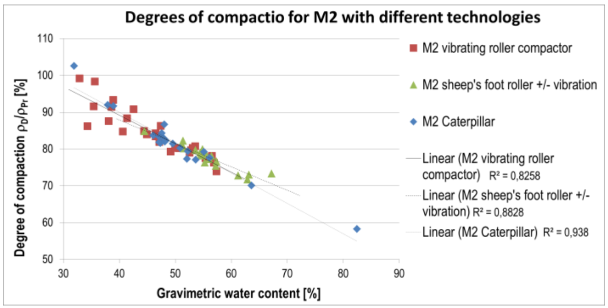

Fig. 3. DOC for M2 and different compaction technologies (Cantré and Saathoff, 2013)


Fig. 4. Installation of the rigole, connected to a geosynthetic drainage composite to control the phreatic level


Fig. 5. Rostock research dike with filled polder 2, north view

deviations in the compaction results. This was possible particularly because of the crumbly state of the ripened dredged material. For material with larger loam or clay clots the method would have to be revised.

The placement of the geosynthetics was basically unproblematic. The reinforcement material was placed in sections E and F (east) in two layers on the water side and one layer on the air side. The erosion control products were placed on top of the compacted surface. They were fixed with steel rods for good connection with the soil and then covered with 2-5 cm of crumbly dredged material of the same type as underneath to fill the structure of the erosion control product. The drainage composites were placed in machine direction parallel to the dike axis (drainage water flows in cross-machine direction). On section H, west, a rigole was installed made of a nonwoven geotextile and drainage gravel, which is connected to the geosynthetic drainage composite (Fig. 4). This system was chosen for one of the homogenous sections to be compared with the system with a drainage composite only.

The construction was finished in June 2012. Afterwards the very dry summer interfered with the vegetation cover, however, from September the germination of the applied dike seed mixture progressed quickly. Already at the end of the year 2012 a dense grass cover was present (Fig. 5).

2.4 Investigations on the Research Dike

The eastern dike has been instrumented extensively to measure the seepage into and through the dike core, using tensiometers, volumetric moisture content probes, piezometers and tipping counters. The western dike is mainly used for overflowing tests. Therefore, flexible timber flumes have been installed on the western slopes. First results from the investigations have been published by Olschewski et al. 2014, Saathoff and Cantré, 2014 and .Nitschke et al. 2014.

3. DredgDikes Pilot Dike at the Körkwitzer Bach

The dikes along the *Körkwitzer Bach*, a small river approximately 30 km north-east of Rostock, Germany, flowing into the coastal backwater *Saaler Bodden*, are dilapidated. On a length of approximately 4.5 km the dikes are covered with trees and shrubbery and the crest height has declined due to ground settlements. In some sections the dike can hardly be recognized any more. The soil on both sides of the stream consists of up to 3 m peat over sand. The existing dikes are mainly made of peat which was dug out to build a drainage channel system on the adjacent agricultural land. Mineralisation effects lead to a further deformation of the peat dikes. There is also a pumping station draining a considerable area of land from both sides of the river into the *Körkwitzer Bach*.

There are three possible flood scenarios at the lower part of the *Körkwitzer Bach*: River flood bringing water from the upper catchment, river flooding caused by backwater from the *Saaler Bodden* and land flooding caused by water draining the land on both sides of the stream, which should be coped with using the pumping station. Presently in case of a flood, the water is pumped in circles: Since the dikes are not working any more, the pumped water will flow right back onto the areas to be drained, from where it will be pumped into the river again. This is a massive waste of energy.

A pre-plan for dike reconstruction along the stream had been prepared prior to the project by a local planner estimating comparably high reconstruction costs due to the difficult ground, the risk of floods during the construction time because part of the adjacent areas are even below the sea water level, and the compensation measures with respect to trees and reed as well as the otters living in the area.

To reduce construction costs the use of alternative dike construction material was discussed which lead to the idea to include the measure in the DredgDikes project, defining a part of the reconstructed dike as pilot object using fine-grained dredged materials as dike cover layer. Therefore, a section of approximately 500 m length in the north-east corner of the *Körkwitzer Bach* was chosen, because between the stream and the village of Neuheide there is a polder directly connected to the pumping station which can be seen as a separately functioning area. Here the reconstruction of a small section made most sense with respect to an actual flood protection.

3.1 Planning and Design

Based on the pre-planning documents for the reconstruction of the dikes along the *Körkwitzer Bach* the section for the pilot dike was chosen. The most efficient standalone section is located at the North-Western corner of the stream. In 2011 the planning for the pilot dike section with the use of a dredged material cover started in co-operation between the *Water and Soil Association* "Untere Warnow – Küste", the University of Rostock, *Chair of Geotechnics and Coastal Engineering* and the local planning firm *WastraPlan*.

In the frame of the pre-planning a ground investigation was performed and a maximum settlement of 0.5 m was predicted. The final design height of the small dike is 1.0 m above sea level, thus the dike crest should be 1.5 m high directly after construction.

A standard cross-section was developed involving a construction road of 0.60 m on top of a woven reinforcement geotextile, which will be also the dike core. On top of the core a layer of 0.90 m of ripened fine-grained, organic dredged material is placed (Fig. 7). The geotechnical characterization of the used dredged material is summarized in Table 3.

According to EAK 2002 (2007) material M2 generally fulfils the criteria of a dredged material (harbour sediment) to be used in a sea dike cover (Table 3). However, the dike is rather a combination of a sea and river dike and thus also the German guideline for river dikes DWA-M 507-1 (DWA, 2011) and the German standard DIN 19712 (2013) are relevant. DIN 19712 indicates that dike construction material for the stable dike body should not exceed an organic matter content (OM) of 4%. Cover material which is at the same time used as surface sealing system has to contain a defined low water permeability, they have to be resistant against erosion and suffusion. Also, they need to be long-term resistant and should not be impaired by mechanical, climatic, chemical and biological influences. Also the materials need to be tested regarding acceptable shrinkage due to drying.

An important planning issue finally was the FFH area which is assigned to the stream including its reed belt on both sides (Fig. 6). This makes it a particularly sensitive area when it comes to constructions. The environmental permit was finally given in the second half of 2013, after three years of preparation.

Table 3. Selected geotechnical properties for the pilot dike

	S2	EAK 2002
Clay [%]	15 – 24	≥ 15
Sand [%]	32 – 44	≤ 40
Water content w [%]	64 – 78	
Organic matter OM [%]	7 – 8	≤ 20
Lime content LC [%]	1 – 2	
c_u [kPa][1)]	17 – 33	≥ 15
φ [°][2)]	30 – 40	
c [kN/m²][2)]	10 – 19	
k_f [m/s]	2E-09	
OD [g/cm³]	1.06 – 1.13	
w_{opt} [%]	45 – 51	

[1)]Results from vane shear tests.
[2)]Results from direct shear tests

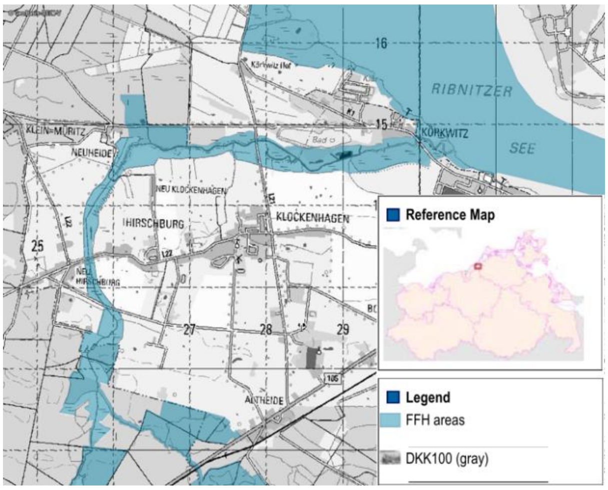

Fig. 6. Location of the Körkwitzer Bach and FFH areas along its banks (GeoBasis-DE/M-V).

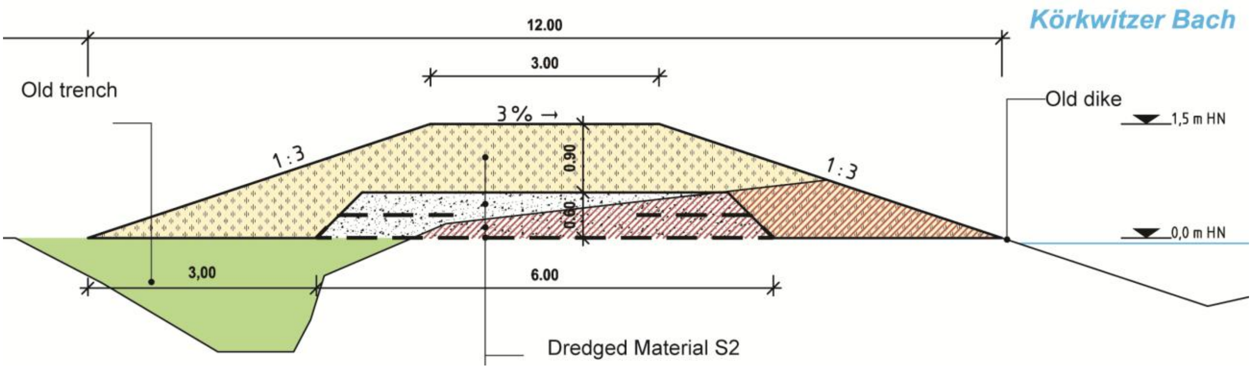

Fig. 7. Standard cross-section for the reconstruction of the dike at the Körkwitzer Bach (WastraPlan 2013)

Fig. 8. Construction of the dike core on geosynthetic and wire placement underneath the dike 12-2013

Fig. 9. Flooded construction site 01-2014

Fig. 10. Frozen construction site 02-2014

3.2 Construction of the Pilot Dike

In summer 2013 the first 4000 m³ of dredged material was transported to the site to be available at the date of the construction start. This caused damages to the only access road – a touristic riding and cycling path between Neuheide and Hirschburg. The path was reconstructed in the frame of the project.

On 27 November 2013 the construction of the test dike started. At first the drainage trench parallel to the dike was relocated because the reconstructed dike will partly rest on top of the old trench filled with soil from the old dike. Then the old dike was removed in sections and the construction road was built on top of the woven geotextile placed on the formation. Since the sandy gravel material used for the construction road has a low erosion resistance, part of the cover material was placed at the banks for erosion protection (Fig. 8). Both the sand and dredged material were compacted using a sheep's foot roller compactor. The construction road was finished by 20 December 2013.

Works were resumed on 13 January after a particularly warm and wet period; however, high water and ice impeded further construction until the end of March (Fig. 9+10). WILL BE UPDATED IN THE FINAL VERSION.

3.3 Investigations at the Pilot Dike

The pilot dike will be subject to long-term monitoring and investigations. During the installation the degree of compaction was analysed in all installation layers. In the frame of the monitoring programme samples from the dike will be analysed in the geotechnical laboratory of Rostock University, Chair of Geotechnics and Coastal Engineering.

The dike is being instrumented with a variety of sensors. Wires and aluminium strips were placed underneath the dike (Fig. 6) and between the sand core and the dredged material cover. In this way the thickness of the different layers can be determined using a cable detection device and the georadar method. Additionally, settlement gauges will be installed on the surface to record the surface deformation. The combination of all recordings will provide a comprehensive picture of the deformation of the respective sections.

To control the seepage through the dike body standpipes will be installed every 50 m from the crest into the sand core of the dike. Also, two sections will be equipped with tensiometers in the cover layer to receive information about the saturation of the dredged material. Together with water level gauges on both sides of the dike (water level of the *Körkwitzer Bach* and of the drainage trench on the western side) as well as precipitation and temperature sensors (both air and soil temperatures) the instrumentation generates data that can be used for future modelling of the system.

4. Discussion

4.1 Rostock Research Dike

The installation and compaction tests showed a better compaction result with the use of roller compactors compared to the caterpillar tracks only. However, for material M2 the difference was quite small, presumably due to the lower water content during installation compared to that of M1. Still it can be seen in Fig. 3 that the main dependency of the compaction results is on the water content rather than on the compaction method. That means that the materials did not have the same water content for all tests which makes a direct comparison difficult. To be sure to receive a good and homogenous compaction a roller compacter should thus be used; for efficiency, the compaction with a caterpillar only is also possible, particularly on slopes with inclinations flatter than 1:3.

Also, a higher risk of non-uniform compaction was assumed initially, which would result in larger standard deviations. However, there is a lower spread of the caterpillar compaction data for M1 and a slightly higher spread for M2. Both are not significant. Thus the assumption could not be verified.

First results regarding the geosynthetic reinforcement of the cover layer to reduce cracking show a positive effect of the reinforcement. Generally there is less seepage water recorded for the reinforced cross-sections. This will be subject to further investigations, such as excavations on the slopes, climate chamber experiments to study the different cracking behaviour of reinforced and non-reinforced samples.

After the construction was finished in May 2012 there was a dry period of nearly three months with no considerable precipitation. Drying effects at the dike surfaces lead to shrinkage and associated cracks. The analysis of the crack development is difficult now that the vegetation covers the dike surfaces. This issue will also be subject to further investigations.

Regarding the correct installation of the erosion control products used there seems to be an issue with the correct filling of the erosion control product in practice: Generally the mat would be filled with crumbly soil material, only just covering the product. However, when putting the soil over the mat there will always be some areas with thicker layers. These areas seem to be critical with respect to overflowing resistance shortly after seeding when the grass roots have not yet reinforced themselves into the RECP and thus leading to a defined shear plane on top of the product.

4.2 The Pilot Dike

On the test dike ferric oxides leaked from the dike toe together with the leakage water, colouring the soil at the dike toe auburn. This is no environmental threat, however, it does not look nice for the public not knowing about the colour's background. This has become a concern at the pilot dike, although the ferric oxide leakage was significantly more obvious on material M1 compared to M2 and M3 and the pilot dike material S2 does not necessarily have the same problem. Still, this will be subject to investigations and monitoring.

The dredged material S2 is similarly fine-grained as material M2, thus there is a risk of shrinkage and surface cracking during dry periods. There are technological measures to mitigate this problem, e.g. by tilling and re-compacting the surface as soon as cracking develops (EAK 2002). This will also be subject to the monitoring plan.

Based on DIN 19712 material S2 would not be suitable as dike core material (OM > 4 %), although it has been proven that the organics in these materials are long-term stable according to the AT_4 test for waste materials (Morscheck et al. 2014). For the use in the sealing layer the permeability is sufficiently low, however the danger of shrinkage cracking has to be focused on. Therefore, two aspects should be discussed: The use of materials with stable organics of more than 4% and methods to mitigate desiccation cracks if they occur.

5. Conclusions

The research dikes built in the frame of the DredgDikes project gave opportunity to investigate installation and compaction issues regarding the dredged materials and geosynthetics used. Also, first results about the materials' performance in flood conditions are available.

1. The installation on both the test dike and the pilot dike showed the general applicability of the materials as well as a comparably easy handling of the soils.
2. All materials chosen are generally suitable for application as dike cover material after EAK 2002. Only the shrinkage cracking is an issue that needs further investigation.
3. The best compaction on the test dike was achieved when installing the dredged materials with a caterpillar in layers of 0.30 m and compacting them with a roller compactor.
4. The use of the degree of compaction DOC as a quality control measure is problematic due to the inhomogeneities of the materials. Therefore, additional measures will be used to control the pilot dike construction.
5. Installation tests of the erosion control products showed that it is essential not to cover them with too much top soil so that the grass roots can cling into the material even in an early stage of turf development shortly after germination.
6. The cover layer reinforcement shows a tendency for better performance with respect to infiltrating water compared to the sections without reinforcement. This issue will be subject to further investigation.

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Notation

RECP	Rolled Erosion Control Product
OM	Organic Matter
DOC	Degree of Compaction
UR	University of Rostock
GUT	Gdansk University of Technology
M1…3	Dredged materials in the research dike
S2	Dredged material in the pilot dike

c_u	Initial shear strength
φ	Angle of internal friction
c	Cohesion
k_f	Hydraulic conductivity
OD	Optimal dry density
w_{opt}	Optimal water content
EAK	Recommendations for the design of coastal protection constructions
FFH	EC Directive 92/42/EEC on the conservation of natural habitats and of wild fauna and flora

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