Investigation of Dredged Materials in Combination with Geosynthetics Used in Dike Construction

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Abstract

In the project DredgDikes with partners from Poland and Germany different dredged materials from the South Baltic Sea region are investigated for their application in dike construction. Two large-scale experimental dikes have been built, one in Germany and one in Poland. Additionally, a large variety of laboratory tests and experiments have been performed and a considerable monitoring test programme will be followed. This paper contains a general description of the project as well as first results from a laboratory flume test, field investigations on seepage and the information about a planned climatic chamber experiment, all performed at the University of Rostock, where the focus is laid on fine-grained dredged materials in combination with geosynthetics solutions. The flume experiments showed a very high strength of the dredged materials samples with grass cover. The first seepage test at the large-scale test dike in Rostock showed good performance of the geosynthetic drainage solution applied as well as the stability of the dredged material with respect to rapid drawdown of the water level. The comparison of measurements inside the dike and a seepage model showed considerably higher hydraulic conductivity in the field compared to that determined in the laboratory, however still in the range suited for coastal dike cover materials. To investigate the cracking behaviour of the ripened fine-grained dredged material a climatic chamber experiment has been set up which is also discussed briefly.

1. Introduction

Large amounts of sediments are removed from the water bodies in maintenance and environmental dredging projects. The major amount of these dredged materials is relocated in the water bodies [1–2]. 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. Then they are considered a waste material after European regulations. Still, the materials are a valuable resource for agricultural use, landscaping or even as construction materials, particularly when they are not contaminated. Fine-grained organic dredged materials are usually processed (dewatering and ripening) before they can be re-used. Experience shows, that some of the materials are well suited for the recultivation layers of landfill cappings, where high erosion resistance and extremely high water retention capacities could be observed [3].

This resulted in the proposal to use this kind of dredged material as coastal dike cover material. The usual dike cover materials like marsh clay (North Sea) and glacial limy marl (Baltic Sea) are becoming short and they have to be mined, usually in environmentally sensitive regions, while the dredged materials are available and need to be used beneficially. A cooperation project was developed to investigate these materials both in the laboratory and in large-scale outdoor experiments.

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Keywords: dredged material, geosynthetics, dike, seepage, reinforcement, erosion control.
The project DredgDikes was initiated by the University of Rostock (UR), Chair or Geotechnics and Coastal Engineering, and Gdansk University of Technology (GUT), Chair of Geotechnics, Geology and Maritime Engineering. Three more partners from Germany are responsible for specific investments and environmental analysis within the project. The project is part-financed by the European Union’s South Baltic Programme. 15 associated organisations from Poland, Germany, Latvia and Lithuania are involved in the project. The main aim of the project is to get different solutions to use dredged materials 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 the 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 [4]. This paper focuses on the German part of the project.

The dredged materials investigated in Rostock come from the Warnow river mouth area. They are processed on the city of Rostock’s spoil fields, where they are classified and certified for re-use. High natural water contents even after several years of ripening may lead to shrinkage and cracking phenomena after installation. Geogrid reinforcement within the dike cover may cope with this problem. The erosion resistance against rainfall seems to be good, however, the erosion resistance against overflowing of bare or partly vegetated dredged materials is yet unknown. Also the materials can be comparably inhomogeneous. Therefore rolled erosion control products (RECPs) are applied to strengthen the surfaces of the dike slopes.

Finally, the consortium investigates whether a ripened top-soil-like dredged material can be used in a homogenous dike setup and whether innovative drainage solutions help to control the seepage line during hydraulic loading of the dike.

2. Scientific Background

The use of fine-grained and organic dredged materials as construction material is a rather new idea and particularly their application in dike construction, where safety plays a major role. After present recommendations, these dredged materials should only be used in dike construction if they meet particular geotechnical criteria, comparable to other dike construction materials [5–6]. The geotechnical characteristics of the dredged materials investigated here show low permeability and sufficient strength in the lab. Other parameters, like the Attenberg limits or the decomposition time after Weißmann [5] cannot be determined in reproducible quality, so that other criteria may need to be developed. In dry periods there is also a tendency of the materials to shrinkage and cracking among the materials with high natural water contents, even after several years of ripening on the drying fields. Therefore investigation is needed with respect to the general applicability of the materials, the necessary characterisation of materials to be used in dike construction (including characteristic laboratory tests), efficient installation technologies, the improvement (reinforcement) of the materials to reduce cracking, and methods to prove and if necessary enhance the materials’ erosion resistance, which is the most important issue when it comes to sea dike covers [7].

At the University of Rostock, there has been a long tradition of dredged materials research, including their dewatering and ripening [8–9] and particularly with the beneficial use of ripened dredged materials in agriculture, landscaping and for the recultivation of landfills [3], [10]. Based on this experience it was proposed that some of the fine-grained dredged materials should be applicable as dike cover materials. This lead to a first project, involving a full scale dike construction on the Drigge spoil field on the island of Rugia [11] and finally to the project DredgDikes, in which the presented results were derived.

There is also a long tradition of geosynthetics research in Rostock, already starting in the GDR time [12] and still continuing, with focus on geosynthetics used in the interface of geotechnical and hydraulic engineering [13–15] and with respect to dike reconstruction [16].

In recent years, research and application of dredged materials applied in dike construction has also been performed in Hamburg at the TU HH-Harburg [17], the University of Hamburg [18], the Hamburg Port Authority, and the Federal Waterways Engineering and Research Institute BAW. In Bremen dredged materials have been applied in dike construction through Dike associations and Bremenports [19].

3. Dredged Materials Investigated

In the German test dike five different dredged materials have been used to build dike core, cover layer and homogenous dike cross sections. The dredged materials are ripened dredged sediments from the Warnow river delta in Rostock. They have been processed on the City of Rostock’s spoil field “Radelsee”. The spoil field consists of two dredging polders, long enough for the separation of different grain size classes: pure sand (M5 in Table 1), mixed “top soil” (M3), and fine-grained organic materials (M1/2). After one year of dewatering the materials are usually removed from the polders and set up to
heaps on the ripening fields. The ripening is particularly important for the fine-grained organic materials. M1 has been ripened for 6 years prior to installation, while M2 has been ripened for only 3 years when installed in the test dike. 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 [11].

Table 1. Selected geotechnical properties [20]

<table>
<thead>
<tr>
<th>Property</th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M5</th>
</tr>
</thead>
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<tr>
<td>Clay [%]</td>
<td>27</td>
<td>24</td>
<td>15</td>
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<tr>
<td>Silt [%]</td>
<td>43</td>
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<td>31</td>
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<tr>
<td>Sand [%]</td>
<td>30</td>
<td>41</td>
<td>54</td>
<td>98</td>
</tr>
<tr>
<td>Water content [%]</td>
<td>65</td>
<td>60</td>
<td>46</td>
<td>12</td>
</tr>
<tr>
<td>PI [ ]</td>
<td>4–22</td>
<td>9–24</td>
<td>3–4</td>
<td>–</td>
</tr>
<tr>
<td>Organic cont. [%]</td>
<td>10.5</td>
<td>9.5</td>
<td>5.5</td>
<td>–</td>
</tr>
<tr>
<td>$c_u$ [kPa]*</td>
<td>120</td>
<td>30</td>
<td>120</td>
<td>–</td>
</tr>
<tr>
<td>$\rho_w$ [g/cm³]</td>
<td>1.16</td>
<td>1.30</td>
<td>1.36</td>
<td>1.65</td>
</tr>
<tr>
<td>$w_{opt}$ [%]</td>
<td>41</td>
<td>37</td>
<td>31</td>
<td>15</td>
</tr>
</tbody>
</table>


*Results from vane shear testing

4. Experimental Dike with Geosynthetics Solutions

The large-scale experimental 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 cross-section. Most of the cross-sections have been realised both on the Eastern and the Western dike.

Fig. 1. 3D view of the Rostock test dike, from West

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 tip counters. The Western dike is mainly used for overflowing tests. Therefore, wooden flumes will be installed on the Western slopes and the water level inside the polders will be risen so that water flows over the crest-areas particularly lowered to realise overflow only on defined parts of the slopes. The base of the construction is sealed by a geosynthetic clay liner for a defined lower hydraulic boundary condition. Five different dredged materials and four different geosynthetic solutions have been installed in the German test dike. Table 2 gives an overview of the materials used in each cross-section.

To reduce shrinkage cracking in the dike cover layer, a geosynthetic reinforcement product was installed. 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 three-dimensional geosynthetic erosion control grid (Huesker Fortrac 3D) was used (Grid in Table 2). Without reinforcement large cracks are expected that may reach the sand core. With reinforcement installed, a larger number of smaller cracks are expected, not exceeding the reinforcement (Fig. 2).

To strengthen the surface erosion resistance of the greened slopes with respect to wave attack or overflowing / overtopping events, a rolled erosion control product (Colbond Enkamat) has been installed on several cross-sections (C, E, F in Fig. 1), covered by up to 5 cm of dredged material before greening (RECP in Table 2). The above three-dimensional 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. 3).
Table 2. Overview of materials installed in the test dike

<table>
<thead>
<tr>
<th>Section</th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M5</th>
<th>RECP</th>
<th>Grid</th>
<th>Drain</th>
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<tbody>
<tr>
<td>A</td>
<td>x</td>
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<td>x</td>
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<td>x</td>
</tr>
</tbody>
</table>

M1/2/3/5: see table 2. RECP: Rolled erosion control products; Grid: three-dimensional erosion control grid for reinforcement; Drain: geosynthetic drainage composite; A...H compare Fig. 1

* homogenous cross-sections, no sand core

In the homogenous cross-sections of polder 3, innovative drainage solutions were installed using a geosynthetic drainage composite (Colbond Enkadrain). 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 will drop to the drainage layer and come out at a defined line along the slope or dike toe (Fig. 4).

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Fig. 2. Sand core & geogrid reinforced dredged material cover. Without geogrid large cracks. With geogrid more smaller cracks not exceeding the geogrid

Fig. 3. Sand core & erosion protected dredged material cover. Without erosion control blanket surface erosion due to overflowing. With erosion control no erosion
5. Selected Experiments

A large variety of experiments are planned within the project, most of which will be performed in 2013 and 2014. First laboratory flume experiments and an initial full-scale seepage test have been performed of which some important results will be discussed in the following. A climate chamber experiment has been designed, which will be presented here for the first time.

5.1. Laboratory Flume Experiment

A small scale laboratory flume has been developed and used to investigate the erosion resistance of unvegetated and vegetated dredged material samples with and without erosion control product [21]. The results of the experiments will be used to design full-scale overflowing tests of the test dikes. The flume is approximately 3 m long and 0.25 m wide with an inclination of 1:3 (Fig. 5). It is instrumented with discharge, water level and velocity measurement probes. A window at the side allows the observation of the flow. A laser scanner is used to determine the eroded surface of the bare soil samples, which showed considerable erosion phenomena at small flow rates.

In the flume a maximum shear stress of 210 N/m² (determined based on the measured flow height and slope inclination) and a maximum flow velocity of 2.3 m/s have been realised. The flow conditions were generally turbulent (Re > 4000) and supercritical (Fr > 1) to simulate extreme conditions that would occur during overflowing and overtopping of dike embankments.

The unvegetated soil samples were tested with a very low discharge of 2.4 m³/h/m, for a duration of 30 minutes, applying a shear stress of 6.7 N/m² and another 10 minutes with a discharge of 11.6 m³/h/m (Fig. 6). Material M2 showed the best results among the three tested materials, with an average of 1.1 mm of erosion depth after 30 minutes. Another test series was performed with material M2 and an erosion control product placed on top, covered with 3 cm of dredged material. The measured results were comparable for the erosion of the cover material until the erosion control product lay bare. Then the erosion rate dropped considerably, proving the performance of the product.
The vegetated samples were produced in the green houses of our Faculty of Agricultural and Environmental Sciences at Rostock University. The grass mixture consists of a standard dike seed mixture with 3% legumes added. The root density in the range of $3 \times 10^{-3} - 1 \times 10^{-2} \text{ g/cm}^2$ was very good according to Vavrina [24]. Depending on the roughness of the surfaces, shear stresses between 160 and 210 N/m² (360 m³/h/m) were applied, considerably higher than in standard dimensioning literature and even higher than the results reported from the ComCoast project, where none of the grass covers could be destroyed with overflowing rates of 108 and some even withstood 270 m³/h/m [22]. Disturbances of the grass cover like fissures and holes did not have any effect on the erosion resistance since the grass covered these disturbances completely (Fig. 7).

5.2. First Full-Scale Seepage Experiment

Three months after completion of the test dike, the first full-scale seepage experiment has been performed in polder 3 (homogenous cross-section H, Fig. 8). Therefore the polder was filled with water nearly to extend in less than 3 hours. The installed dredged material M3 is the one with the highest permeability among the materials investigated.
In addition to the installed geosynthetic drainage composites (see above) a rigole has been added in the Western dike to drop the seepage line. Six tensiometers, one moisture sensor, and one piezometer were installed in each of the two dikes. An additional piezometer was used to measure the water level in the polder (Fig. 9).

The polder was refilled to the initial level after 11 days to compensate seepage water (Fig. 10, red line – piezometer free water level). 21 days after filling the polder was drained through the bottom outlet within less than 30 minutes without any damage to the soaked slope surface.

With this first test a reasonable seepage line could be obtained with the used sensors and theirs arrangement. In Fig. 11 both the modeled (blue) and the measured seepage line (orange) after 21 days are compared. To receive a good agreement between the measured and calculated seepage lines, a hydraulic permeability of $5 \times 10^{-6}$ m/s was used in the calculation – a considerably higher value than that determined in the laboratory (compare [11]). Further investigation is needed to find the
reasons for this deviation. The experiment also showed that the drainage composites and rigole are working well to lower the seepage line within the dike body.

5.3. Planned Climate Chamber Experiment

A climate chamber experiment has been set up to investigate the cracking development in a dredged material sample. Also, geogrid reinforcements are installed (Fig. 12) to gain more detailed information about their performance with respect to their influence on the cracking behaviour during shrinkage.

Therefore samples of 80×30×50 cm³ (width, depth, height) are installed in a sample box with a Perspex plate at the front to digitally record the crack development (video) and to measure the occurring deformations photogrammetrically. The samples are then put into a large-scale climate chamber (12 m² floor space) which can simulate a wide range of temperatures, wind, precipitation and radiation.

![Fig. 12. Setup of the climate chamber experiments. A: with reinforcement. B: no reinforcement. At each sensor point: temperature, suction pressure, moisture content](image)

The experiments will be used to observe what happens in average and extreme weather conditions. Both slow and quick drying as well as freeze-thaw and wet-dry cycles will be simulated. The results of the unreinforced samples will be compared to those gained by Beyer et al. [17], who used dewatered dredged materials from the Hamburg sludge processing plant METHA for their investigations.

6. Conclusions

The overflowing tests in the laboratory flume with turbulent and supercritical flow conditions showed a medium erosion resistance of the dredged materials investigated, the best results being experienced with material M2, while the vegetated samples all showed considerably high erosion stability, even in case of damages to the surface. Additional experiments will be performed in Spring 2013 to look at particular phenomena, like the performance of partly vegetated samples or samples where the grass has been dried out. Also the effect of cracks in longitudinal and cross-sectional direction will be investigated in the small scale. These results will be used to design the large-scale experiments on the test dike, which will start in Summer 2013.

The full-scale seepage experiment performed so far shows satisfactory results. The measured seepage line was also modeled and the agreement between the two results was good and show a hydraulic conductivity of about $5 \times 10^{-6}$ m/s for the rather sandy dredged material M3. In Spring 2013 a series of such full-scale experiments will be performed at the Rostock test dike, in all three polders and with different settings with respect to the filling and drawdown time and the impounding time.

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References


