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LOAD-BEARING CAPACITY OF A SELECTED DREDGED MATERIAL – EVALUATION FOR ITS APPLICABILITY ON THE EAST ZINGST DIKE PROJECT

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Abstract. A 6 km long dike has been established on the East Zingst peninsula to provide protection of the Bodden lagoon coast against storm flood. On top of the dike a cycle and hiking trail had to be built. The dike consists of a sand core, covered with cohesive soil. The local authority requires that dredged material should be used for the cover. The requirements of dredged material for covering a dike were fulfilled. The load bearing capacity for the trail installation was unknown. For this purpose a test area with four different structures were built and a soil mechanic test program including plate-loading-tests were executed. As a result the used dredged material was not able to fulfill the required load bearing capacity to build a trail on it.

Keywords: dike, dredged material, load bearing capacity, rural roads, plate-loading-tests, modulus of deformation

1. Purpose of project and construction

In the context of the complex East Zingst storm flood protection/renaturation project, the storm flood protection system of Zingst, which had become significantly weaker over the last few years, was redesigned.

The Zingst peninsula forms the natural geological spit separating the Darss-Zingst Bodden Chain of lagoons from the Baltic Sea. Due to the narrowing of the flow stream from the Baltic Sea, the hydrodynamic exposure of the lagoons decreases the further away they are located from the open sea. During storm floods, the water level in the lagoons is therefore several decimetres below that of the Baltic Sea. The protective structures along the Bodden lagoon coast therefore need not to be as high as those along the Baltic coast.

The above project is aimed at establishing a system of dikes on the East Zingst peninsula to provide permanent protection of the Bodden lagoon coast against storm flood damage. At the same time, the project was to regenerate the damaged ecosystems on East Zingst. These objectives were achieved by constructing a six kilometre long sea dike running parallel to the local road to Pramort. The dike was constructed in two phases. The planned standard structure in both phases of the sea dike is identical and can best be described as follows:

The dike height is + 3.55 m NHT. The water side slope has a gradient of 1:12, while the air side slope has a gradient of 1:6. After removal of the topsoil and soil replacement in sections, a sand core is built, covered in cohesive soil to protect against erosion. The water side erosion protection layer is 0.90 m thick. At the Bodden lagoon side, it measures 0.60 m. It is covered in topsoil and planted. In the first construction phase, marl is chosen to build the erosion protection layer.

A cycle and hiking trail is built on the dike crest. The dike maintenance road is built along the base of the dike at the Bodden lagoon side (see fig. 1).

The dike and the maintenance road were built at the request of StALU Vorpommern. The dike-top path was built at the request of the municipality of Ostseeheilbad Zingst who is responsible for its maintenance.

As the State of Mecklenburg-Vorpommern requires that dredged material is re-used as dike cover material, material from the dredged material containment and processing facility “Schnatermann” of the city of Rostock had to be incorporated as a cohesive cover layer in the East Zingst sea dike, the second section of the project. It became however clear that this would only be possible, if it could be shown that the properties of the dredged material would be equivalent to those of cohesive cover soil.

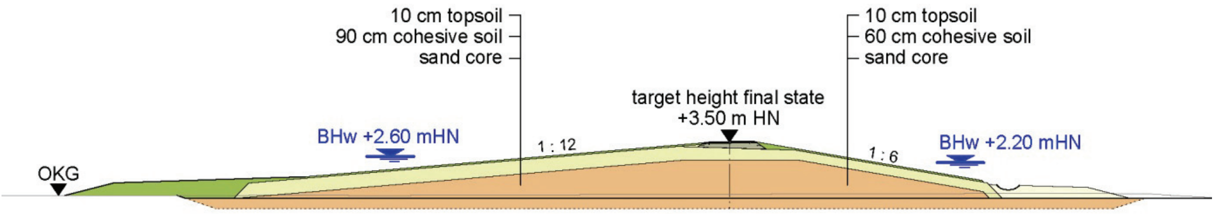

Fig 1. Standard cross-section of the East Zingst dike

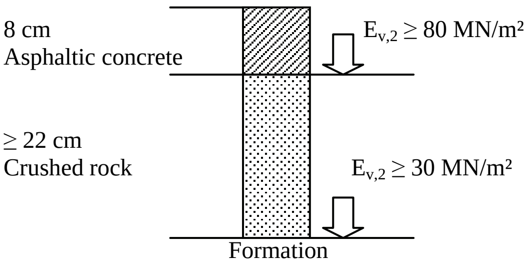

Fig 2. Road construction

For the East Zingst sea dike, this meant that the dredged material has to provide suitable for the road construction, especially when considering the fact that the trail to be built on top of the dredged material was to be completed by a different developer, namely the municipality of Zingst.

According to technical rule DWA-A 904 "Richtlinie für den ländlichen Wegebau" [Guidelines for the construction of rural roads], the modulus of deformation of the dredged material formation must be Ev,2 ≥ 30 MN/m². The formation on the crushed rock layer must be Ev,2 ≥ 80 MN/m².

If these requirements could be met, the trail could have been built according to the above guidelines for rural road construction.

2. Requirements to be met by dredged material for use as dike construction material

The dike cover must perform the following functions:

- Protection of sand dike core against wave and other erosion
- Reduction of dike percolation without guaranteeing absolute tightness
- Formation of substrate for dense turf cover

As regards the actual project, the material must provide sufficient strength for the construction of the road.

For adequate protection of the sand dike core, the dredged material must have sufficiently high initial shear strength c_u. According to the EAK recommendations, the initial shear strength should be ≥ 15 kN/m².

The shear strength c_u is correlated to the packing density of the material. According to the Requirements for cohesive dredged material, a packing density of D_{pr} ≥ 95 % must be achieved, which is possible provided that the material is installed in layers and its water content is close to the optimum water content.

The required percolation reduction is achieved by the low permeability k_f, which is determined by the grain size of the material. Dredged material normally meets the required low permeability value, as its clay content is high while its sand content is low. To meet the requirements, the clay content should be ≥ 15 % while the sand content should be ≤ 40 %. The clay content should only be determined after all humus and carbonate has been destroyed.

Dredged material tends however to shrink considerably. Deep shrinkage cracks can have a detrimental effect on the already low tightness of the cover layer. The placement water content w should therefore be between that on the air side $w_{(95\%\ Dpr,\ air)}$ and that of the water side $w_{(95\%\ Dpr,\ water)}$ (i.e. $w_{(95\%\ Dpr,\ air)} \leq w \leq w_{(95\%\ Dpr,\ water)}$).

According to the specifications of the authorities in charge of the project, the dredged material was to be installed in layers of 90 cm in thickness, with an expected shrinkage by approx. 10 cm due to drying. Damage to the dike due to deep shrinkage cracks was deemed acceptable, as the protection function of the sea dike was of secondary importance and the project was designed to obtain data as regards the use of dredged material in dike construction. As the dredged material contains some organic material, it can be expected that a dense turf will grow on the substrate.

No consistent data was available as regards the load bearing capacity of the dredged material in conjunction with road construction.

Dredged material to be used as building material for dikes must conform to the following requirements:

- Total organic carbon (TOC) [%]: 3 ≤ TOC ≤ 10
- Clay content (d < 0.002 mm) [%]: ≥ 15
- Sand/gravel content (d > 0.063 mm) [%]: ≤ 40
- Placement water content w [%]:
  w(95% Dpr, air) ≤ w ≤ w(95% Dpr, water)
- Degree of compaction Dpr [%]: ≥ 95
- Layer thickness [cm]: ≤ 25
- Camber height of cover layer: 10 cm

3. Determination of load bearing capacity of dredged material - test layout and procedure

For the determination of the load bearing capacity of the dredged material to be integrated, a test area was constructed near the Schnatermann dredging field.

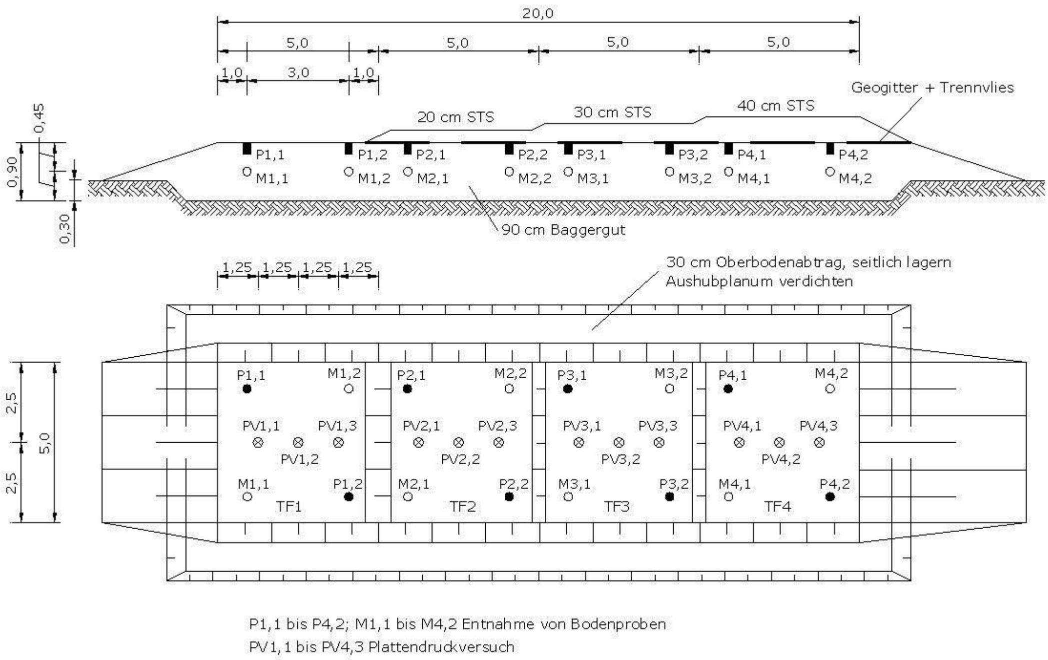

Fig 3. Structure of test area and location of sampling point and load plate tests [U 2]

The test area has a size of 5.0 x 20.0 m and was divided into four sections of equal size and different structure (see fig. 3):

Test area section 1:
90 cm dredged material, compacted
Test area section 2:
90 cm dredged material, compacted
geogrid with separation fleece
20 cm crushed rock layer, compacted
Test area section 3:
90 cm dredged material, compacted
geogrid with separation fleece
30 cm crushed rock layer, compacted
Test area section 4:
90 cm dredged material, compacted
geogrid with separation fleece
40 cm crushed rock layer, compacted

In these test area sections, plate-loading tests were performed in order to determine the $E_{v,2}$ value and the $E_{v,1}/E_{v,2}$ ratio. In order to achieve reliable results, three plate-loading tests were planned for each test area section.

A comprehensive soil mechanics test programme was completed during the test period. The following soil mechanics lab tests were envisaged:

- Determination of placement water content
- Determination of TOC
- Determination of Proctor density
- Determination of dry density and degree of compaction
- Determination of liquid, plastic and shrinkage limits
- Determination of initial shear strength c_u
- Determination of grain size distribution with humus and carbonate destruction

The test area and the tests were performed in the following sequence:

- Removal of 30 cm topsoil layer, storage to the side of the test area
- Compaction of excavation planum
- Installation of dredged material in layers with subsequent compaction. Soil sampling for placement water content determination during installation of centre soil layer.
- Soil sampling for above soil parameters after installation of the dredged material
- Installation of geogrid and separation geotextile on Formation in test area sections 2, 3 and 4
- Installation and distribution of crushed rock layer (20, 30 or 40 cm, as specified above)
- Compaction of crushed rock layer with vibration plate
- Performance of plate-loading tests

All earth-moving work was carried out in February 2011 under dry and frost-free weather conditions. The soil mechanics lab and field tests including sampling were performed under the auspices of the Chair of Environmental Geotechnics, Landscape Construction and Coastal Engineering of the University of Rostock.

During the night of the 10/11 February, the area was affected by rain. At the Warnemünde weather station, 1.5 mm of rain was measured during that night.

Fig 4. Sampling of installed dredging spoil

Fig 5. Test area after completion

It is therefore unlikely that the dredging spoil was in any significant way affected by this. The first plate load test was performed on 11 February 2011 in test area section 4.

4. Test results

4.1 Determination of placement water content

The water content was determined following DIN 18121-1. The placement water content of the dredged material was determined in 16 disturbed soil samples (4 for each test area section). The first 8 samples were taken after the material was installed to half its final height at approx. 45 cm. The remaining 8 samples were taken after the final construction height of 90 cm was reached. The water content of the respective samples in the tables below is the arithmetic mean of 3 single samples. The results are compiled in Tables 1 and 2.

4.2 Determination of liquid, plastic and shrinkage limits

The liquid, plastic and shrinkage limits were determined following DIN 18122-1 and DIN 18122-2 for the following 4 disturbed soil samples (1 sample per test area section). The results are compiled in Table 3. The measured water content was between 66.2 and 70.2 %. The mean water content was 68.4 %.

Table 1. Water content of dredged material in samples taken at half the final construction height

Test area section	Sample	w [%]
1	M 1,1	66.9
	M 1,2	67.4
2	M 2,1	68.7
	M 2,2	67.3
3	M 3,1	68.7
	M 3,2	70.2
4	M 4,1	69.5
	M 4,2	69.9

Table 2. Water content of dredged material in samples taken 5 to 20 cm below planum

Test area section	Sample	w [%]
1	P 1,1	67.7
	P 1,2	66.2
2	P 2,1	70.2
	P 2,2	66.2
3	P 3,1	70.1
	P 3,2	67.7
4	P 4,1	69.5
	P 4,2	68.0

Table 3. Results of liquid, plastic and shrinkage limit measurements

Parameter	Test area section			
	1	2	3	4
	P1,1	P2,1	P3,1	P4,1
Water content w [%]	69.9	75.4	68.2	71.4
Liquid limit w_L [%]	88.5	92.4	91.3	88.4
Plastic limit w_P [%]	52.8	56.7	58.7	53.3
Plasticity index I_P [%]	35.7	35.7	32.6	35.1
Consistency index I_C [-]	**0.52 (soft)**	**0.48 (liq.)**	**0.71 (soft)**	**0.48 (liq.)**
Soil type (DIN 18196)	UA	UA	UA	UA
Shrinkage limit wS [%]	46.7	48.1	45.8	45.2
Shrinkage rate [%]	34.1	35.2	35.2	35.2

Table 4. Results of laboratory vane shear tests (initial shear strength)

Test area section	Sample no.	Water content [%]	Mean of three individual tests max. shear strength c_{fv} [kN/m²]
1	P1,1	73.3	36.3
	P1,2	66.3	48.1
2	P2,1	71.6	34.8
	P2,2	63.8	53.8
3	P3,1	72.0	37.3
	P3,2	68.0	37.1
4	P4,1	68.5	46.4
	P4,2	68.0	38.2

4.3 Determination of initial shear strength

The initial shear strength was determined in the laboratory by means of vane shear tests following DIN 4094-4 and the "Richtlinien für die Prüfung von mineralischen Weichdichtungen im Verkehrswasserbau" [Guidelines for the testing of mineral dike sealing materials] (RPW), edition 2006 published by the German Federal Waterways Engineering and Research Institute BAW. The tests were carried out with eight undisturbed soil samples in the cutting cylinder along the cutting edge.

Table 4 shows the maximum shear strength c_{fv} of the soil at first shearing without correction factors (according to DIN 4094). To determine the water content, a separate sample was taken immediately after the shear test from the soil cylinder near the incision points of the vane.

4.4 Determination of Proctor density

The final degree of compaction of the installed dredged material was determined in 8 Proctor tests according to DIN 18127. The results are compiled in table 5.

4.5. Determination of dry density and degree of compaction of the dredged material

To determine the final degree of compaction D_{PR}, it is necessary to measure the Proctor density as well as the dry density of the installed and compacted dredged material. The dry density was determined following DIN 18125-2 and sampling with cutting cylinders. The results are compiled in table 6. The determined degrees of compaction were only between 66.9 % and 73.2 % (mean: 69.0 %).

Table 5. Results of Proctor tests

Sample	Water content w_{PR} [%]	Proctor density ρ_{PR} [g/cm3]	95 % of Proctor density		
			ρ_d [g/cm3]	min. w [%]	max. w [%]
P 1,1	37.3	1.230	1.168	-	42.2
P 1,2	38.4	1.185	1.126	-	45.8
P 2,1	39.8	1.178	1.119	-	-
P 2,2	37.1	1.247	1.185	-	-
P 3,1	39.5	1.211	1.151	-	-
P 3,2	37.9	1.229	1.167	-	-
P 4,1	38.4	1.226	1.165	35.1	43.2
P 4,2	39.2	1.219	1.158	-	-

Table 6: Results of dry content and degree of compaction measurements

Sample	Placement water content	Wet Density ρ	Dry Density ρ_d	Proctor density ρ_{PR}	Degree of compaction $D_{PR} = \rho_d / \rho_{PR}$
	[%]	[g/cm³]	[g/cm³]	[g/cm³]	[%]
P 11	73.3	1.426	0.823	1.230	**66.9**
P 1,2	66.3	1.442	0.867	1.185	**73.2**
P 2,1	71.6	1.331	0.776	1,178	**65.6**
P 2,2	63.8	1.465	0.894	1.247	**71.7**
P 3,1	72.0	1.404	0.816	1.211	**67.4**
P 3,2	68.0	1.404	0.836	1.229	**68.0**
P 4,1	68.5	1.441	0.855	1.226	**69.7**
P 4,2	68.0	1.425	0.848	1.219	**69.6**

4.6 Determination of total organic carbon (TOC)

The TOC was determined in tests performed at the Agricultural Investigation and Research Centre (LUFA) in Rostock at the request of the University of Rostock based on DIN ISO 10694. At LUFA Rostock, the TOC was determined in an elemental analyser where the soil samples are heated to 1250° C. The results are compiled in table 7.

Table 7: Measured TOC values (in %)

Test area section	Sample	TOC
1	P 1,1	4.7
	P 1,2	4.8
2	P 2,1	5.2
	P 2,2	5.0
3	P 3,1	4.8
	P 3,2	4.4
4	P 4,1	4.7
	P 4,2	5.1

4.7 Determination of grain size distribution with humus and carbonate destruction

The tests for the determination of the grain size distribution with humus and carbonate destruction were performed by the staff of the Professorship in Soil Physics and Resource Protection at the Faculty of Agricultural and Environmental Sciences of the University of Rostock.

The grain size was determined by means of the Köhn pipette method. The air-dried soil samples first underwent a treatment in which its cohesive components such as carbonates and organic substances were removed. Tetrasodium pyrophosphate was used as the soil dispersant.

The sand fraction was removed by means of wet sieving. The silt content (fine, medium, coarse silt) and the clay fraction was determined by elutriation. The soil types were determined based on the fraction shares. The results are compiled in table 8.

Table 8: Grain size distribution after humus and carbonate destruction (in %)

Grain size	Sample no.			
	P 1,1	P 2,1	P 3,1	P 4,1
C	17.5	24.1	20.6	23.9
fSi	4.6	9.0	8.6	9.0
mSi	14.1	16.9	18.8	18.8
cSi	35.5	20.8	21.0	18.7
fSa	18.3	19.9	19.3	18.7
mSa	8.8	8.1	9.7	8.6
cSa	1.3	1.1	2.0	2.2
∑ Sa	28.4	29.1	31.0	29.5
Soil type (DIN)	U, fs, t, ms’	U, t, fs, ms’	U, t, fs, ms’	U, t, fs, ms’

4.8. Determination of modulus of deformation (plate-loading test)

The modulus of deformation was determined by means of static load plate tests according to DIN 18134. A load plate with a diameter of 300 mm and PDV 2 measuring and evaluation software owned by Strassentest oHG was used. A loaded 3-axle tipper truck of the construction contractor was used as the counterload for the plate-loading tests. Given the test area section size of 20 x 5 m, the measuring points were chosen along the longitudinal axis of the section.

Fig. 6: Failed load plate test in test area section 2

It was initially envisaged to perform 12 plate load tests (3 per test area section). Due to the great deformation of the substrate (to the limit of the measuring range of the displacement sensor), it was however only possible to complete 6 tests. The results of the load plate tests are compiled in table 9.

5. Conclusions

1. The dredged material used for the construction project taken from the Schnatermann dredged material containment and processing facility meets the main requirements for use as dike cover material.
   TOC [%]:
   $3 \leq 4.4 \ldots 5.2 \leq 10$
   Clay content (d < 0.002 mm) [%]:
   $17.5 \ldots 24.1 \geq 15$
   Sand/gravel cont. (d > 0.063 mm) [%]:
   $28.4 \ldots 31.0 \leq 40$

Table 9: Results of modulus of deformation tests

Measuring point in test area section	max. settlement s [mm]		Modulus of deformation		E_{V2} / E_{V1} ratio
	Initial loading	Second loading	E_{V1} [MN/m2]	E_{V2} [MN/m2]	
PV 4,3	11.6	13,0	**10.2**	13.0	**1.27**
PV 4,2	9.9	10.9	**15.9**	11.9	**0.75**
PV 4,1	11.2	11.7	**10.2**	15.4	**1.51**
PV 3,3	37.2 1)	37.2 1)	**3.7**	7.2	**1.96**
PV 3,2			not performed		
PV 3,1	36.5	39.5 1)	**3.9**	6.2	**1.59**
PV 2,3			not performed		
PV 2,2	37.9 1)		aborted		
PV 2,1			not performed		
PV 1,1 to 1,3			not performed		

1) Measuring range of displacement sensor exceeded (stop reached)

2. The initial shear strength cfv of the installed dredged material is between 34.8 kN/m² and 53.8 kN/m² (mean: 41.5 kN/m²) determined in the test also meets the EAK requirements of minimum 15 kN/m².
3. The placement water content is however much higher than permissible. It is between 66.2 % and 70.2 % with a mean of 68.4 %.
4. The optimum water content at a degree of compaction of D_{pr} = 95 % was determined to be as follows: 35.1 % at the air side and between 42.2 % and 45.8 % at the water side of the proctor compaction curve.
5. The water content of the installed dredged material is thus **50 to 60 %** above the required maximum water content.
6. The determined Proctor densities of between 66.9 % and 73.2 % (mean: 69.0 %) are well below the required value of $D_{pr} \geq 95$ %. This is mainly due to the high water content. Given these high values, greater compaction on site and smaller layer thicknesses would not be sufficient to achieve the desired degree of compaction.
7. The highest modulus of deformation $E_{v,2}$ (max. 15.4 MN/m²) was measured in test section 4 with a 40 cm crushed rock layer installed on top of a geogrid. As this value amounts to only about 20 % of the required value of $E_{v,2\ req.} \geq 80$ MN/m².
8. In test area section 3 with a crushed rock layer of 30 cm on geogrid, the measured modulus of deformation amounted to merely 7.2 MN/m², or 9 % of the required value.
9. In test area section 2, only a single test was attempted that had to be aborted without results. It was subsequently decided not to perform any test in test area section 1 (section without crushed rock layer).
10. It must however be noted that the $E_{v,2}$: $E_{v,1}$ ratio in the test area sections 4 and 3 were extremely low at 1.27 to 1.96. This is a clear indicator for the proper compaction of the crushed rock layer. For the determined $E_{v,2}$: $E_{v,1}$ ratio values a degree of compaction $D_{pr} \geq 103$ % can be expected; the required degree is 100 %. This means that the dredged material with its low compaction but also with its general properties is responsible for the low modulus of deformation $E_{v,2}$.
11. The examined dredged material of the "Schnatermann" containment area does not meet the specified load bearing capacity requirements and is therefore not suitable for installation on the dike crest of the East Zingst sea dike. This is mainly due to the excessively high water content of the material that prevents effective compaction.
12. Even at an installed density of $D_{pr} \geq 95$ %, it cannot be assumed that the required modulus of

deformation values can be achieved, as this would first need to be proven in further tests.

13. Due to its hydraulic conductivity, erosion resistance and shear strength it is suitable to use as a dike cover material on the slopes of this project.
14. For future construction projects where dredged material of the "Schnatermann" dredged material containment is to be used and where the load bearing capacity of this material plays a significant role as regards the strength of the construction, it is necessary to perform additional suitability tests. Based on the findings made in the test area for the East Zingst sea dike, it appears that only material with a water content close to the optimum value would possibly be suitable for installation. As a rule, batches with a higher water content must be classified as unsuitable.
15. Prior to a construction project including the installation of dredged material, it is recommended to determine the suitability of the material by measuring its water content and performing Proctor tests. To be considered for use, the natural water content w of the dredged material should be as follows: $w_{(95\%\ Dpr)}$ air side ≤ w ≤ $w_{(95\%\ Dpr)}$ water side.
16. Where dredged material taken from the dredged material containment "Schnatermann" is to be used as a cover material for dikes, it is recommended to refrain from building any roads or paths (hiking trails, crest roads, maintenance roads, etc.) on top of this material on the dike crest. Such constructions should always be built on a mineral soil substrate.

Nomenclature

EAK Recommendations for coastal protection constructions
StALU State Agencies for Agriculture and Environment of Mecklenburg and Lower Pommerania
LUFA Agricultural Investigation and Research Centre
TOC Total Organic Carbon
$E_{v,1}$ modulus of deformation (first load)
$E_{v,2}$ modulus of deformation (reload)
D_{pr} Degree of compaction (Proctor density)
c_u initial shear strength
ρ_d dry density
ρ wet density

References

BAW, 2006, Guidelines for the testing of mineral dike sealing materials (RPW)

DIN 18121-*1: 1998-04: Water content, part 1: Determination by drying in oven*

DIN 18122-1: 1997-07: Consistency limits – Part 1: Determination of liquid limit and plastic limit

DIN 18122-2: 2000-09: Consistency limits – Part 2: Determination oft he shrinkage limit

DIN 18125-2: 1999-08: determination of density of soil, part 2: field tests

DIN 18127: 1997-11: Proctor-test

DIN 18134: 2001-09: plate load test

DIN 19683-02: 1973-0: Methods of soil analysis for water management for agricultural purposes - Physical laboratory tests - Determination of grain size distribution after pretreatment using sodium pyrophosphate

DIN 4022: 1987-0: Designation and description of soil and rock, part 1

DIN 4094-4: 2002-01: vane testing

DIN ISO 10694: 1996-0: Determination of organic carbon and total carbon after dry burning (elementary aanalysis)

DIN ISO 11277: 2002-08: Determination of particle size distribution in mineral soil material - Method by sieving and sedimentation

EAK 2002-*Empfehlungen für die Ausführung von Küstenschutzbauwerken [Recommendations for coastal protection constructions],* Die Küste, vol. 65, Coastal Engineering Research Council, 2002

StALU MM, 2010, *Requirements for cohesive dredged material for use as dike; research results*

University of Rostock, 2011, *Chair of Environmental Geotechnics, Landscape Construction and Coastal Engineering: Laboratory test report project no.: 12-08-034-4*

Zöller, Ralf, 2005, *Zur Eignung von Baggergut aus Elbe und Weser als Kleiersatz in Deichbau. in: HTG-Kongress2005, Bremen, S. 561 - 570*