DREDGED SEDIMENT CHARACTERISTICS AFTER TREATMENT BY GEOSYNTHETIC DEWATERING TUBES

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ABSTRACT

Geosynthetic dewatering tubes have become the state of the art technology for dewatering large volumes of dredged materials. The worldwide use of dewatering tubes is continuously increasing due to the high process capacity and the excellent achievable results. In order to document the efficiency of the geosynthetic dewatering tube system the two first harbor maintenance projects executed with dewatering tubes in Germany, Verden (Wilke 2011) and Husum, were scientifically supervised by the University of Rostock. The smaller project in Verden was executed in 2010 and dealt with the remediation of approximately 1000 m³ of harbor sediment. The project in Husum was executed in two phases during 2013 and 2014: one trial section treating 6,000 m³ sediment in 2013 and the follow-up section compromising 50,000 m³. One focus of the scientific analysis considered the time-related achievable dry solid content after pumping the conditioned sediments into the tubes. Additionally, basic analysis including sieve curve analysis, loss of combustion, densities and calcium content has also been performed. As the tubes can be installed in a stacked pyramidal pattern comprising several tube layers, another question raised was the resulting undrained shear strength of the dewatered material. A hand-held shear vane was used to test this parameter at several locations within the different tube layers. The results of the two projects concerning the dry solid content development will be compared and summarized.

Keywords: Dewatering, sediments, geosynthetic tubes.

INTRODUCTION

The dredging business is continuously growing. Even during the economic downturn, the worldwide dredging turnover showed an increase of 13% between 2008 (€10.3bn) and 2013 (€11.68bn). The dredging turnover in 2013 shows an increase of 2.7% compared to 2012 (IADC 2013). World trade is widely recognized as the most important driver for the dredging industry and therefore one important factor is port and waterway maintenance. For example in Germany each year 46 million m³ of sediment has to be removed from German watercourses (BMVBW 2004). This includes maintenance dredging as well as environmental remediation measures. The handling and the sediment utilization often creates problems as soon as the dredged (contaminated) material has to be deposited on land. This is mainly due to the high water content of the hydraulically extracted material and contaminants including tributyltin (TBT) and/or heavy metals. To facilitate the handling and to reduce the volume of the sediment it is normally dewatered by means of mechanical devices or stored in dredged spoil material disposal areas. Alternative and effective dewatering and encapsulation technique with enlarged treatment capacities have been established using geosynthetic dewatering tubes. Apart from the process capacity the main criteria for the efficiency of the dewatering technique is the achieved dry solid content of the dewatered material. Consequently, one main focus of the scientific analysis was the achievable dry solid content over time after pumping the conditioned sediments into the tubes. In order to estimate the bearing capacity of the dewatered material inside the tubes the undrained vane shear strength was determined. Moreover some other basic analyses (e.g. sieve curve analysis, loss of combustion, densities, calcium content, etc.) have been performed. The outcome provided some observation of the principal phenomena of this specific dewatering technique and some indicative values for the time-related dewatering behaviour could be derived. Furthermore, some first insights of the dry solid content/undrained shear strength relationship could be detected.

VERDEN SPORTBOOTHAFEN (VERDENER MARINA), VERDEN, GERMANY

The Aller River, the Weser's largest tributary, is a federal waterway in the Unteraller area. This particular section, near Verden, contains the marina for the Verden motorboat association (Verdener Motorboot-Verein e.V.k), which dates back to 1971. It is a smaller facility with a capacity of 50 boats in total. The ship length within the basin is limited up to 10 m. Approximately 1000 m^3 of sediment had formed in the marina basin over the decades. Prior to

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the project execution, sediment samples had been taken and analyzed with regard to potential contaminants. Due to the higher contents of zinc and cadmium detected, the sediment was classified as contaminated. The main sediment fraction consisted of silt with loss on ignition values of 11% to 14%. The in-situ dry solid (DS) content of the deposited silty material was in the range of 30.6% per weight up to 37.5% per weight (average of 34.05% per weight).

Project set-up

The project equipment consisted of three main components:

- Dredger with a mixture capacity of approximately 400 m³/h to 450 m³/h.
- Polymer preparation and admixture unit.
- Three dewatering tubes manufactured of polypropylene.

Initially, a buffer unit was interconnected between the dredger and the polymer preparation and admixture unit. Afterwards the buffer was taken out and the polymer was directly injected into the dredged material stream. The polymer unit was furnished with a DS probe, continuously measuring the DS content of the incoming slurry. Based on this input value the polymer admixture was automatically adjusted by the container based polymer unit. An inductive flowmeter was incorporated in order to permanently record the discharge. The dewatering tubes were placed on a prepared and lined dewatering pad. A pump sump was used to re-feed the filtrate into the harbor basin.

Experimental program and analysis

The filtrate quality was checked for turbidity and suspended solids. Due to the organic content the filtrate was slightly colored. However, there was no need for establishing a downstream mobile water treatment plant or for prohibiting direct re-feeding.

The following geotechnical tests were performed for the dewatered material stored within the three tubes according to German Standards:

- Determination of grain-size distribution according to DIN (Deutsches Institut fuer Normung) 18123
- Determination of density of soil according to DIN 18125
- Water content - Part 1: Determination by drying in oven according to DIN 18121
- Determination of ignition loss according to DIN 18128
- Consistency limits - Part 1: Determination of liquid limit and plastic limit according to DIN 18122
- Subsoil - Field testing - Part 4: Field vane test according to DIN 4094-4

For three mixed samples of each sampling point the following analysis have been executed:

- Determination of particle size distribution in mineral soil material - Method by sieving and sedimentation according to DIN ISO 11277
- Determination of density of solid particles according to DIN 18124

Each tube was furnished with three inlets distributed equally along the longitudinal axis of the tube. The required sediment samples have been taken by using these (in total nine) access points (i.e. three per tube). In order to achieve the time related dry solid content, ten sediment sampling runs were performed on a weekly basis. The sampling period started 12th May and was completed 22nd July.

Results

In total, a slurry volume of 3798 m³ was put through the polymer unit. The sediment volume extracted from the harbor was finally controlled by a survey: 900 m³ had been removed. A geodetic survey lead to a final residual volume of 550 m³ encapsulated in the dewatering tubes.

The polymer consumption was approximately 790 l of emulsion, which is equal to an active ingredient of 395 kg consumed. Relating the dry solids contents of the preliminary investigations to the final volume extracted results in a treated total mass of bone dry solids of approximately 387 tons. Therefore, the polymer consumption can be expressed as 1.02 kg per ton dry solids.

The results of the vane shear measurements of the contents inside the tube were in the range of 6 kN/m² to 14 kN/m².

The dewatered material density varied from a minimum of 1.427 t/m³ to a maximum of 1.624 t/m³ (average of 1.549 t/m³) with an averaged solid particle density of 2.6 t/m³. The ignition loss was determined as 3.33% to 9.17% (average of 5.96%) which was slightly lower compared to the obtained values during the preliminary investigation.

The data gained from the time dependent dry solid content analysis is shown in Figure 1. Within the first three weeks, a strong increase of the dry solid content was detected. Afterwards minor changes took place. Even for the final analysis there is still a deviation detectable from a minimum value of 41.3% to a maximum value of 89.6%. The final overall averaged dry solid content is 59.5%.

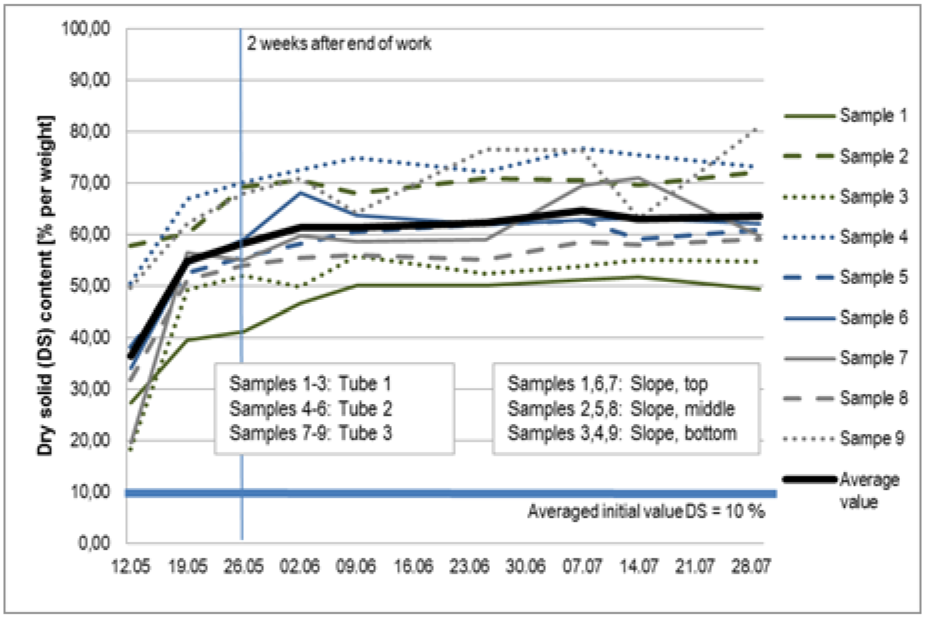

Figure 1. Time-related development of the dry solid content of the dewatered material sampled at the inlets distributed along the longitudinal axis of the three dewatering tubes.

Discussion

It can be concluded that the Marina cleaning in Verden was a success. The achieved dry solid (DS) contents in such a short period of time were excellent in comparison for example to the time consuming treatment by dredged material disposal sites or drying beds. Furthermore, the monitoring over approximately three months showed that by using the dewatering tubes most of the static and gravimetric dewatering process was completed within 3 weeks after end of active dewatering tube operation.

As a consequence of the hydraulic extraction method the in-situ sediment volume of 900 m³ with an averaged DS content of 34.1% was diluted down to 3798 m³ with a DS content of ~10%. Finally, the volume was decreased to 550 m³ and the DS content was increased up to an averaged value of 59.5% by using the geosynthetic dewatering tube technology.

Linking the in-situ volume to the finally measured tube containment volume an overall volume reduction factor of 40% can be concluded. For this result a comparably low polymer consumption was required.

Apart from the intermediate storage function, which might be of great importance for bigger projects with several dredgers, the use of a buffer tank does not seem to be beneficial for smaller dredging projects. It is important to consider a proper project set-up and appropriate equipment.

HUSUM HARBOR, HUSUM, GERMANY

The harbor in Husum is of great importance for the western coastline of the federal state of Schleswig-Holstein in Germany. Located within the outer harbor is a dry dock including a basin for turning maneuvers in front. The material deposited in this area and the access channel was heavily contaminated with the antifouling biocide tributyltin (TBT), which is now banned by the European Union (EU). In order to guarantee future access to the dry dock and the inner harbor the removal of the sediments was necessary. Due to space constraints the construction of a dredged spoil disposal site was not possible. In addition, the designated area for receiving the dredged material was located in a potential inundation zone. Therefore, the use of the dewatering tube system with a substantially reduced footprint and a containment and encapsulation function was deemed the preferred choice. As the project size with an initially estimated in-situ volume of 40,000 m³ to 50,000 m³ was quite remarkable in combination with the novelty of the system to the German sediment management market the German authorities hesitated to tender the complete volume in one step. Therefore, in 2013 it was agreed to perform a real scale trial with a volume of 6,000 m³ to be treated. The German authorities were convinced by the excellent results of the trial and in 2014 the remaining sediment volume of 45,000 m³ was removed by using the geosynthetic dewatering tube system. Based on preliminary investigations the sediment was characterized mainly as silt with a smaller sand content and an ignition loss of approximately 7%. The particle-size distribution curves of seven soil samples can be found in Figure 2.

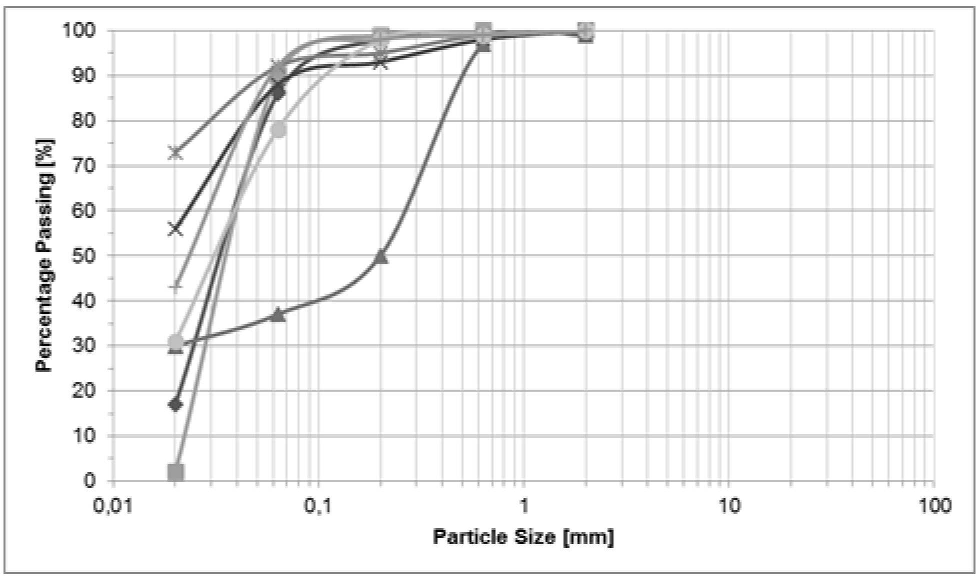

Figure 2. Particle-size distribution curve of seven soil samples taken out of the Husum Harbor in 2012.

By a chemical composition analysis of the sediment samples following heavy metals could be detected:

- Cadmium
- Mercury
- Chrome
- Copper
- Lead
- Nickel
- Zinc and
- Arsenic.

Furthermore, several gasoline derivatives (such as polycyclic aromatic hydrocarbons (PAH)) were found. Additionally polychlorinated biphenyls (PCBs) were detected. However, the main problem consisted in the high concentration of tributyltin (TBT) which originated from the extensive use of TBT containing antifouling paints for the hulls.

Project set-up

In this case an inline polymer injection system in combination with a dredger of 600 m³/h was used. Again the dewatering tubes were placed on a prepared and lined dewatering pad. The filtrate was collected by a drainage ditch and then re-fed into the harbor by a pump.

With regard to the total volume to be treated and the land requirements a stacked tube installation pattern was necessary. In order to simulate the installation conditions for the final project, the pyramidal installation method was also applied for the trial.

Experimental program and analysis

The condition of the tubes more than six months after end of operation is shown in Figure 3, illustrating the pyramidal installation pattern. In total 15 tubes with varying lengths and a circumference of 15.0 m were filled.

Figure 3. View from the South to the North of the first dewatering field six months after end of operation (note the preparation of the dewatering area for the following main section around the previously used tubes).

Due to the greater number of dewatering tubes, not all of them were scientifically analyzed. Two tubes were selected for analysis:

- The southern-most tube of the lower (first) layer.
- The third southern-most tube of the upper (second) layer.

By choosing one tube from the top layer and one tube from the bottom layer it was intended to detect and confirm the assumed different development of the dry solid content and undrained vane shear strengths in different stacked tube layers. For access and sampling points, again, the inlets of the dewatering tubes were used. At each sampling point material was extracted from the top, the middle and close to the bottom of the tube. The vane shear measurements were performed in the same manner. The location of the inlets and sampling points can be found in Figure 4.

Figure 4. Location of the inlets and sampling points of the analyzed tubes at the Southern corner of the first dewatering field.

The samples were taken based on a three-week cycle starting 18th September 2013 and ending on 11th December 2013. The final sampling was undertaken in spring 2014 on 23rd April.

The following geotechnical analyses have been performed for the dewatered material encapsulated within the tubes:

- Determination of density of soil according to DIN 18125
- Water content - Part 1: Determination by drying in oven according to DIN 18121
- Determination of ignition loss according to DIN 18128
- Determination of particle size distribution in mineral soil material - Method by sieving and sedimentation according to DIN ISO 11277
- Determination of density of solid particles according to DIN 18124
- Determination of lime content according to DIN 18129
- Subsoil - Field testing - Part 4: Field vane test according to DIN 4094-4

The samples for the density analysis were taken by means of a test pit on the last day, 23rd April 2014.

Results

The obtained data of the time related dry solid content development is illustrated in Figure 5. The final dry solid content varied from a minimum value of 44.21% at the top of sampling point 4 to a maximum value of 57.44% at the bottom of sampling point 2. The final lowest averaged dry solid content has been found at sampling point 4 with 46.63% whereas the highest averaged dry solid content was detected a sampling point 2 with 55.98%. The final overall DS content averaged across all sampling points and depths was calculated as 51.61%.

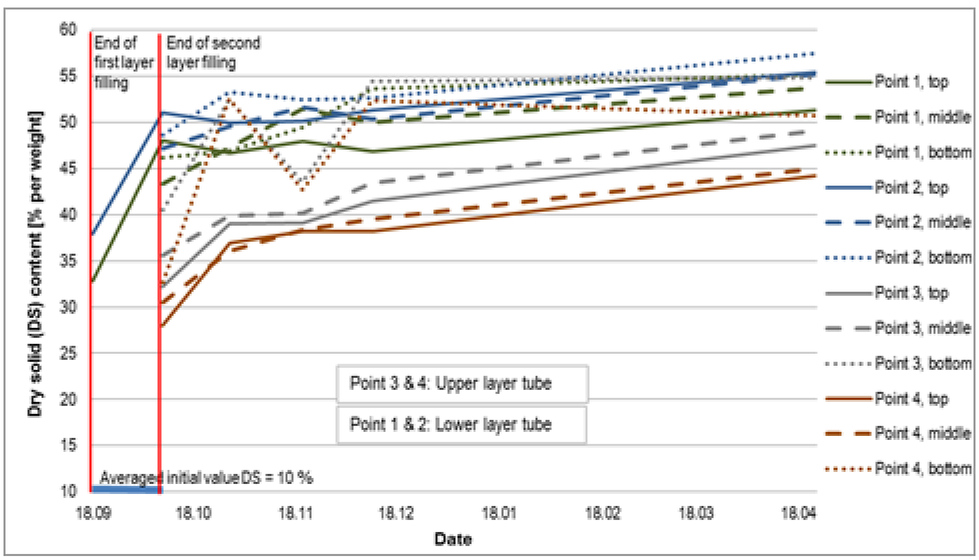

Figure 5. Time-related development of the dry solid content of the dewatered material sampled at two inlets of the lower tube (first layer; sampling point 1 and 2) and of the upper tube (second layer; sampling point 3 and 4).

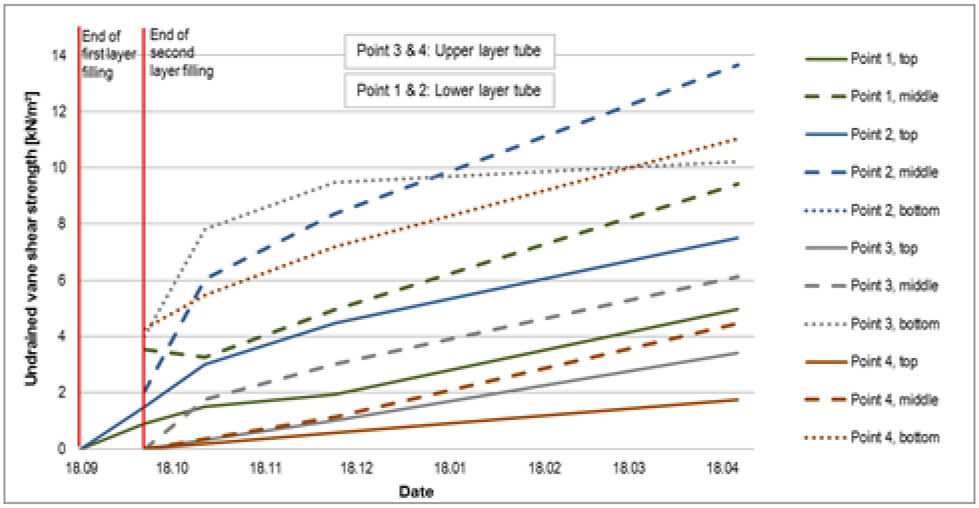

Figure 6. Time-related development of the undrained vane shear strength of the dewatered material measured at two inlets of the lower tube (first layer; sampling point 1 and 2) and of the upper tube (second layer; sampling point 3 and 4).

The measured values of the undrained vane shear strength are shown in Figure 6. The lowest final value of 1.74 kN/m² was measured at the top of sampling point 4 and the highest final value of 13.65 kN/m² was detected at the middle of the lower tube at sampling location 2.

Discussion

With regard to the illustrated results shown in Figure 5 and 6 the following phenomena could be observed:

- It is clear that the increase of the DS content is not fully completed, even after 6 months.
- The undrained vane shear strength variation is significant and strongly related to the location. In most cases the shear strength increases towards the bottom of the tube. The trend between upper and lower tubes is not as clearly visible as assumed. A clear trend is more obvious within the tube itself from the top to the bottom.

Splitting the gathered data shown in Figure 5 into the averaged dry solid content of the lower layer tube and the top layer tube leads to the graph shown in Figure 7. This graph confirms that there is a continuous dry solid content increase which is not fully completed at the end of the data capturing. While the inclination of the graphs is steep for the initial time-period (of around three weeks), it is approaching a horizontal asymptote over the long term. Furthermore, there is a constant offset of approximately 10 % between the development of the dry solid content of the lower and top tube. This is due to the filling of the top layer started around two weeks later. Another reason for the strong DS content increase in the lower layer tube and the offset is the overburden pressure applied by the second tube layer installation. This results in an accelerated dewatering process taking place in the underlying tubes.

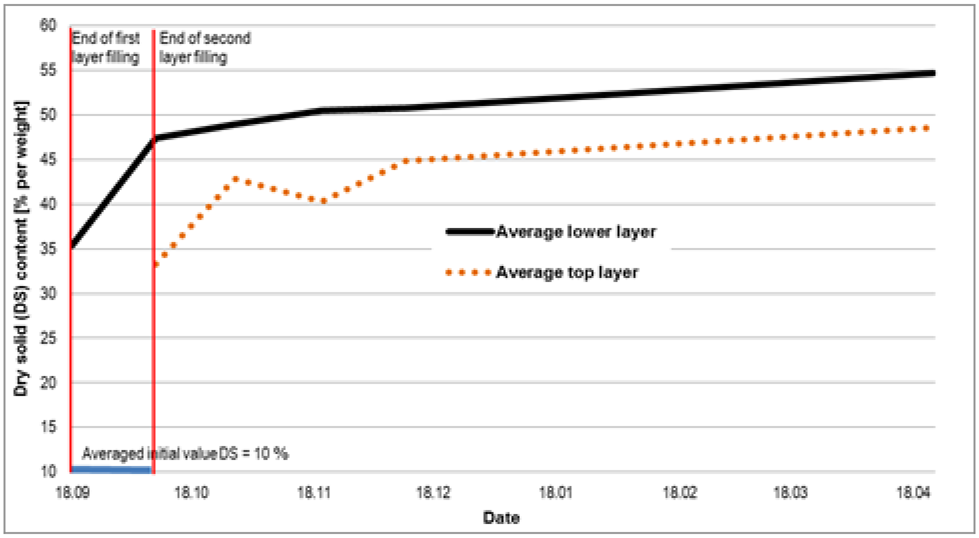

Figure 7. Time-related development of the dry solid content of the dewatered material sampled at two inlets of the lower tube (first layer; sampling point 1 and 2) and of the upper tube (second layer; sampling point 3 and 4).

In accordance with the development of the DS content curves, the trend of the averaged undrained vane shear strength is comparable (see Figure 8).

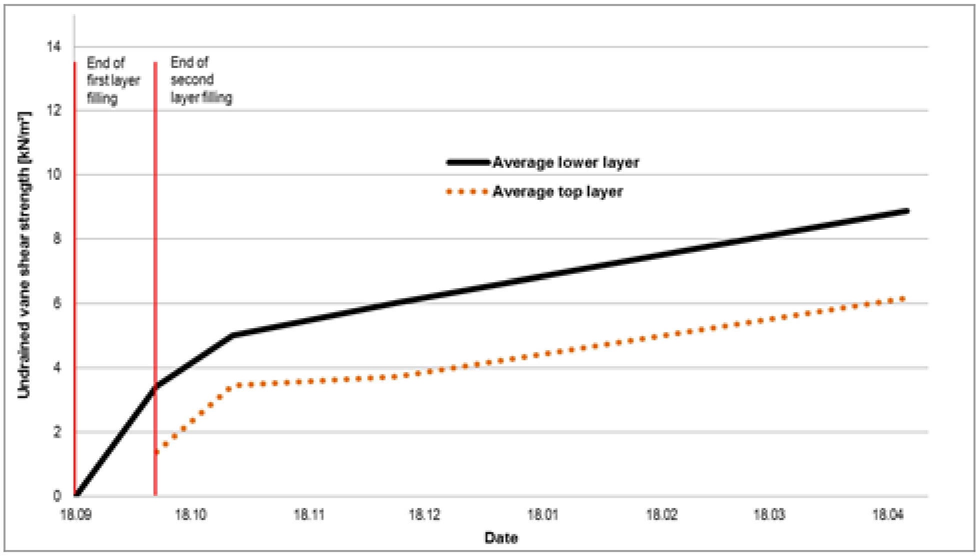

Figure 8. Time-related development of the undrained vane shear strength of the dewatered material measured at two inlets of the lower tube (first layer; sampling point 1 and 2) and of the upper tube (second layer; sampling point 3 and 4).

The increase in shear strength of the dewatered material in the tubes is subjected to a strong increase during the initial phase. In contrast to the dry solid content development, no trend for the approach of an horizontal asymptote can be detected. It seems that the development of the shear resistance of the dewatered material is a long-term related process. However, a clear link between upper and lower tube level is visible.

CONCLUSIONS

The development of the main dewatering performance parameter, the dry solid content, has been continuously monitored for two harbor maintenance projects in Germany. For both projects the tubes stayed in place for several months and were monitored. The time-related averaged dry solid content development curves for each monitored tube of these two projects are shown in Figure 9.

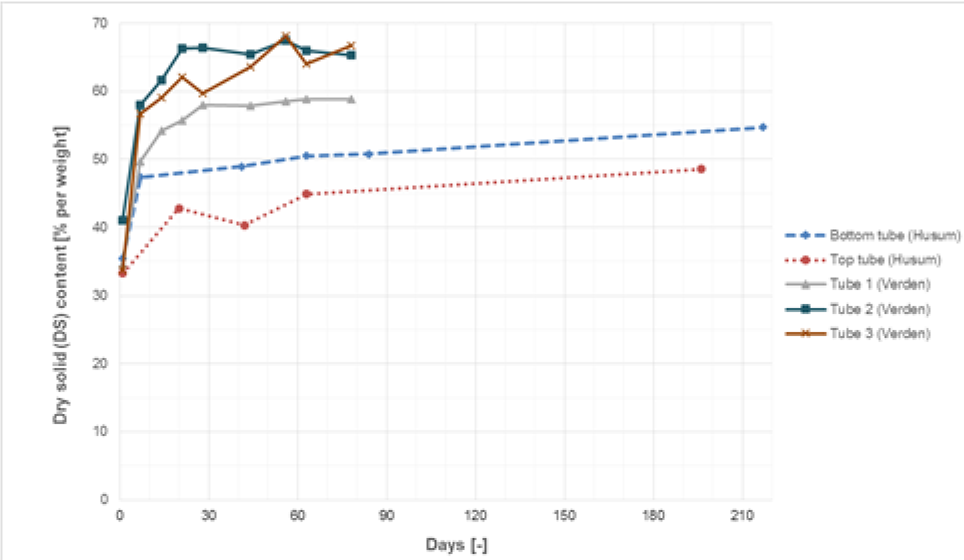

Figure 9. Time-related development of the averaged dry solid content of the dewatered material of each monitored tube for the Verden and Husum project.

The following conclusions are drawn from these projects where the dewatered materials were examined over a period of three and seven months:

- The geosynthetic dewatering tube system works well and is an efficient option for the remediation of both small and large sediment volumes.
- The system is gaining more acceptance in Germany, which is highlighted by an increase in the number of projects.
- The principal trend of the derived DS curves is similar for both projects and all analyzed locations, independent from tube layer or project.
- The absolute values of the DS contents vary. Main variations are due to the different sediment characteristics of the two projects.
- The "dewatering process" for the Verden project seems to be complete whereas it is still ongoing for the Husum project.
- Stacking of tubes (application of a surcharge load) results in an increase in the DS content and the undrained vane shear strength in the lower layer.
- The curve of the dry solid content development approaches a horizontal asymptote. As the projects are located in quite rainy regions, it can definitely be concluded that overall rainfall does not negatively affect the dry solid contents of materials encapsulated within geosynthetic dewatering tubes.

Even if the sediment characteristics were similar, the dewatering time varied. This aspect should be analyzed in greater detail in the future.

As a principal statement with regard to stacked tubes it might be concluded that:

- The lower tubes exhibit greater DS contents and undrained vane shear strength values.
- The upper tubes exhibit lower DS contents and undrained vane shear strength values.

This can be explained mainly with the overburden pressure on the lower tubes originating from the upper tube layer. Moreover, the highest DS contents could be detected at the tube bottoms. However, this has to be confirmed with further measurements and analysis for projects comprising greater than two tube layer levels.

The time-related development of the undrained vane shear strength and its importance for stacking tubes in several layers is an objective for further research.

As an outcome of other monitored and supervised dewatering tube projects it has to be mentioned that the absolute values to be achieved are strongly related to the sediment characteristics.

In summary, it can be stated that the projects can be regarded as great successes and will increase the further use of the efficient and economic geosynthetic dewatering tube system.

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