Port maintenance operations by geosynthetic dewatering tubes – Working principles and practical experience

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Abstract
The scope of this paper is to explain the working principals of geosynthetic dewatering tubes and to highlight the benefits of this system for harbor maintenance operations. This application is further illustrated through the successful execution of a large project in Germany. The harbour maintenance project in Husum was scientifically supervised by the University of Rostock. It was executed in two phases during 2013 and 2014: one trial section with 6,000m^3 in 2013 and the follow-up section of in total 50,000m^3.
For this project the achievable dry solid content was monitored for a longer period of time to document the time related process. In addition some other basic analysis (e.g. sieve curve analysis, loss of combustion, densities, calcium content, etc.) were performed.
As the tubes can be installed in a stacked pyramidal pattern with several tube layers another question raised was the undrained shear strength of the dewatered material. By using a hand-held vane tester this parameter was determined at several locations within the different tube layers.

Keywords: sediment management, dewatering, geosynthetic tubes.

1. Introduction

The dredging business is continuously growing. 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 every year in Germany 46 million m^3 of sediment have to be removed from German watercourses. The handling and the sediment utilization always cause 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 contaminations by TBT or heavy metals, etc. To facilitate the handling of the sediment, it is normally dewatered by means of mechanical devices or stored in dredged spoil material disposal areas. As an alternative and effective new dewatering and encapsulation technique, geosynthetic dewatering tubes can be used.

2. Dewatering tube system components

In order to illustrate the principal system set-up the main components of the dewatering tube system are briefly described. As the system can be adapted to the onsite conditions, a typical dredging and dewatering project set-up is presented. Afterwards the basic dewatering tube mode of operation is explained.

2.1 Dredger

In order to extract the sediment out of the harbour basin a hydraulic dredge is required. For the dewatering tube system the liquefaction of the deposited material is unavoidable. The typical capacity range of dredgers used for direct filling of dewatering tubes is from 90 to 600 m^3/h, depending on the project size. Larger volume dredgers (e.g. 1200 or 1800 m^3/h) are normally applied in combination with a buffer from which the slurry is then diverted to the tubes by a manifold system.

2.2 Flocculation agents

Flocculation agents can be produced from different raw materials including polyacrylamides, starch, chitin and minerals. Organic flocculants, also called polymers, are widely used in the field of dewatering. They are used in water treatment plants, for drinking water, for municipal and industrial water, for paper production, etc. In principal, flocculants enhance the dewatering process by accumulating the suspended finer solid particles to larger flocs. By this process of agglomeration the “water release capacity” of the sludge is massively increased. In most cases, the application of polymers primarily enables the dewatering process.

Figure 1 Effect of blending polymers and effluent water after filtration with high performance filter fabric (from left to right: original sludge; “flocculated” sludge, blended with appropriate polymer; filtrate)

Depending on the particle characteristics (size, charge, etc.) and the slurry properties (pH, concentration of suspended solids) an appropriate flocculation agent can be selected. In general the sludge/polymer ratios are analysed by preliminary laboratory testing and subsequent on-site trials.

2.3 Geotextile dewatering tubes

Geosynthetic dewatering tubes are elliptically shaped, stable long geotextile containment elements designed with a dewatering and storage function. The standard dimensions vary from tubes with a 30 m³ storage volume up to 65 m long tubes with a volume of approximately 1,600 m³ per tube.

Dewatering tubes are furnished with inlets, distributed along the longitudinal axis of the tube. The tube filling is undertaken through these inlets with the processed slurry. Tubes can be installed in a single layer or stacked with multiple layers to form a pyramidal type geometry (see Wilke [4] for case study on stacked tubes).

Geotextile dewatering tubes can only be made out of high strength woven filter fabrics, specifically designed for this purpose. The dimensional stability and integrity of the tube is guaranteed by sufficient tensile strength of the tube fabric in longitudinal and circumferential direction in combination with quality controlled seams. The design of the geotextile tube shell concerning the required tensile strength is explained by Cantré [1] and Leshchinsky [3]. With regard to the dewatering performance there is currently no defined filter criteria applicable. The dewatering behaviour is therefore based on trials and/or experience of the filter performance relating to the relationships between the type of residue, geotextile and flocculants used.

2.4 Dewatering pad

The dewatering tubes have to be placed on an area which is erosion resistant and capable of bearing the loads. Additionally, the dewatering area has to allow for sufficient drainage capacity of the effluent water. Normally the dewatering pad consists of a containment bund, a flexible membrane liner and a gravel drainage layer. In some cases car parks have been converted into "dewatering tube accommodation areas".

The set-up of the dewatering field as well as the geometry can therefore be adapted to specific project requirements. Nevertheless, some points always have to be taken into account:

- The lining system design has to be adjusted to the degree of contamination of the sludge/filtrate.
- The area on which the dewatering tubes will be placed has to be erosion-resistant. Otherwise the effluent water may erode the surface.

For the maximum inclination the dewatering tube producer's specific recommendation should be taken into account. As the large volume geosynthetic units provide both a dewatering and a containment function, the area can be converted into a landfill as the final disposal option. For this specific case the local environmental legislations for landfill construction and closures are valid. Following these basic design rules project specific dewatering tube areas can be constructed.

3. Dewatering tube operation mode

Practically, dewatering by means of geotextile tubes comprises a cyclical process, schematically shown in Figure 2.

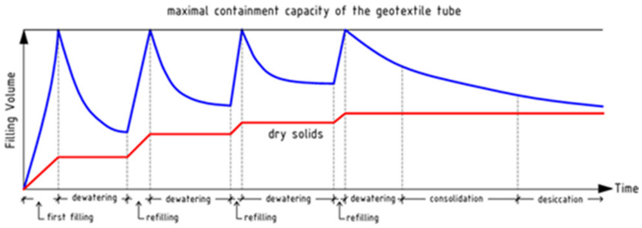

Figure 2 Dewatering cycle by geosynthetic dewatering tubes (adapted and modified from [2] by [4])

During the first filling cycle the dewatering tube is filled to the given maximum initial design height (as determined by the design), and the filling is stopped. The static drainage by gravitation commences as soon as the filling process is halted and following a degree of dewatering the tube can be refilled again. During this cycle the water within the slurry is extracted, therefore the volume is reduced and the solids concentration of the residual dewatered material increases.

The principal process is repeated until the tube is completely filled. Subsequent consolidation and further desiccation occurs. As indicated in figure 2 the filling cycle adopted is one of the factors to consider with regards to the time period considered to achieve optimal filling of the geotextile dewatering tubes. Once the dewatering tubes are fully filled and initial dewatering has occurred further consolidation and reduction of pore pressures continue. Residue particle size distribution and the addition of flocculants to the slurry stream requires further consideration in terms of consolidation. In cases where the sediment consists of coarsely graded material and appropriate flocculation aids are introduced, experience dictates that relatively rapid dewatering and consolidation of the residue contained inside the geotextile dewatering tubes would be expected. In principal a higher organic matter leads to an extended dewatering period. When a multi-layer stacking configuration design is applied, constant over burden pressure applied by the upper dewatering tube on the bottom dewatering tube layers will further contribute to consolidation.

After end of tube operation the residues can be incinerated, re-used or landfilled depending on the degree of contamination and legally permitted subsequent utilisation.

4. The Husum Harbour Project

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 biozide tributyltin (TBT), which is now banned by the 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 obvious 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. In the following the outcome and insights of this trial will be described. Finally 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.

4.1 Project set-up

In this case an inline polymer injection system in combination with a dredger of 600 m³/h was used. 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.

4.2 Preliminary sediment analysis

Based on preliminary investigations the sediment was characterized mainly as silt with a slightly sand content and an ignition loss of approximately 7%. The particle-size distribution curves of seven soil samples can be found in Figure 3.

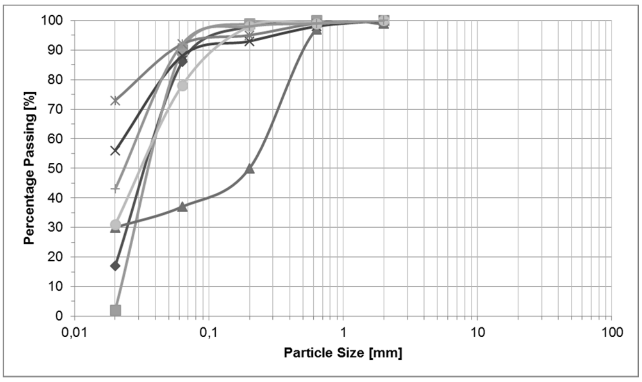

Figure 3 Particle-size distribution curve of seven soil samples taken out of the Husum Harbour in 2012

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) were found. Additionally polychlorinated biphenyls (PCBs) were detected. 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.

4.3 Experimental program and analysis

The condition of the tubes more than six months after end of operation is shown in Figure 4, illustrating the pyramidal installation pattern. In total 15 tubes with varying lengths and a circumference of 15.0 m were filled.

Figure 4 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 could be scientifically analysed. Therefore two tubes were selected:

- 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. As access and sampling points the inlets of the dewatering tubes were selected. 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 5.

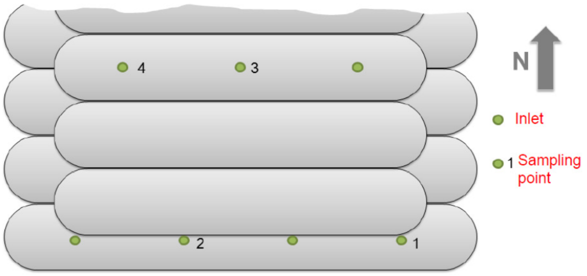

Figure 5 Location of the inlets and sampling points of the analysed tubes at the Southern corner of the first dewatering field

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

4.4 Results

The obtained data of the time related dry solid content development is illustrated in Figure 6. 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 to 51.61%.

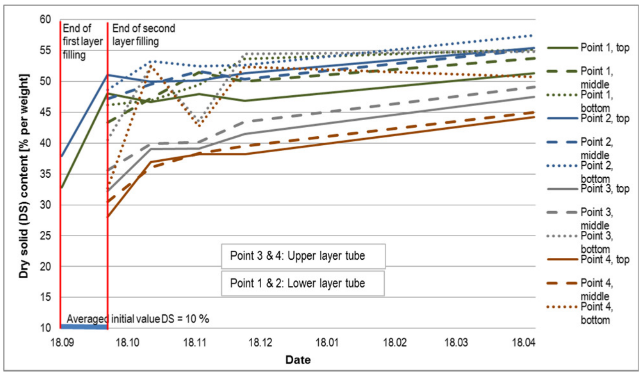

Figure 6 Time related development of the dry solid content of the dewatered material sampled at two inlets of the lower tube (first layer; sampling point 1 and 2) and of the upper tube (second layer; sampling point 3 and 4)

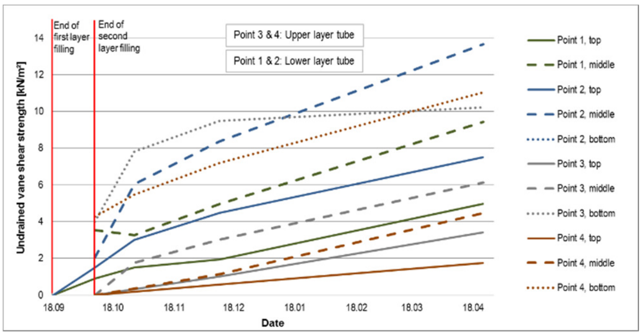

Figure 7 Time related development of the undrained vane shear strength of the dewatered material measured at two inlets of the lower tube (first layer; sampling point 1 and 2) and of the upper tube (second layer; sampling point 3 and 4)

The measured values of the undrained vane shear strength are shown in Figure 7. The lowest final value of 1.74 kN/m² was measured at the top of sampling point 4. Whereas the highest final value of 13.65 kN/m² was detected at the middle of the lower tube at sampling location 2.

4.5 Analysis

With regard to the illustrated results shown in Figure 6 and 7 the following phenomena could be observed:

- It's 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 6 into the averaged dry solid content of the lower layer tube and the top layer tube leads to the graph shown in Figure 8. This graph it 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 in the long run. Furthermore it can be seen that 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 fact that 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 underlaying tubes.

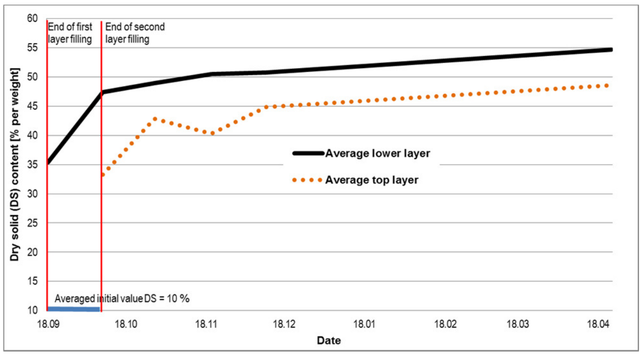

Figure 8 Time related development of the dry solid content of the dewatered material sampled at two inlets of the lower tube (first layer; sampling point 1 and 2) and of the upper tube (second layer; sampling point 3 and 4)

In accordance with the development of the DS content curves, the trend of the averaged undrained vane shear strength is comparable (see Figure 9).

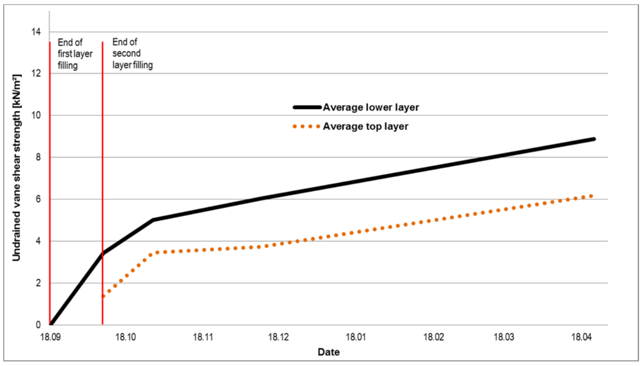

Figure 9 Time related development of the undrained vane shear strength of the dewatered material measured at two inlets of the lower tube (first layer; sampling point 1 and 2) and of the upper tube (second layer; sampling point 3 and 4)

The process is not terminated till the end of the measurements and 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.

5. Conclusions

The development of the main dewatering performance parameter, the dry solid content and the undrained vane shear strength has been continuously monitored for the harbor maintenance project of Husum in Germany. The dewatering tubes stayed in place for several months and were monitored. The following conclusions are drawn from this project where the dewatered materials were examined over a period of eight months:

- The geosynthetic dewatering tube system works well and is an efficient option for the remediation of small and large sediment volumes.
- The system is also gaining more acceptance in Germany, which is highlighted by an increase in the number of projects.
- The absolute values of the analysed parameters differ in relation to the location of the tube. Main variations are due to the location in different layer levels.
- 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 project is located in quite a rainy region, it can definitely be concluded that overall rainfall does not negatively affect the dry solid contents of materials encapsulated within geosynthetic dewatering tubes.

As a principal statement 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 with more 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 project can be regarded as great success and will increase the further use of the efficient and economic geosynthetic dewatering tube system.

6. References

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