HARBOUR MAINTENANCE DREDGING OPERATIONS – RESIDUAL CHARACTERISTICS AFTER TREATMENT BY MEANS OF GEOSYNTHETIC DEWATERING TUBES

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ABSTRACT

In order to increase the knowledge and understanding of the geosynthetic dewatering tube system the two first harbour maintenance projects executed in Germany, Verden (Wilke, 2011) and Husum, where the dewatering tubes have been applied, were scientifically supervised by the University of Rostock. The smaller project in Verden was executed in 2010 and was dealing with the remediation of approximately 1000 m³ of harbor sediment. The other project in Husum, executed in 2013 and 2014, was split into two phases: one trial section with 6,000 m³ in 2013 and the follow-up section of in total 50,000 m³. One main focus of the scientific analysis consisted in the time related achievable dry solid content after pumping the conditioned sediments into the tubes. This topic has been analyzed in detail. Moreover some other basic analysis (e.g. sieve curve analysis, loss of combustion, densities, calcium content, etc.) have been 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 the undrained shear strength at several locations in different tube layers was determined.

1. INTRODUCTION

Every year 46 million m³ of sediment have to be removed from German watercourses (BMVBW, 2004). This includes maintenance dredging as well as environmental remediation measures. The handling and the sediment utilization always causes problems as soon as the dredged (in most cases contaminated) material has to be deposited in the dry. Mainly this is due to the high water content of the hydraulically extracted material. For facilitating the handling and volume reduction of the material normally the sediment is dewatered by means of mechanical devices or stored in spoil areas. As an alternative and effective dewatering and encapsulation method geosynthetic dewatering tubes can be used. The worldwide use of this dewatering technique for dredged sediments is increasing due to the high processing capacity as well as the excellent achievable results in comparison to other treatment methods. The principal mode of operation (Lawson, 2008) as well as the tube basics have been described in great detail, see e.g. Leshchinsky (1996) or Cantré (2002).

In contrast to the internationally established system it is still not well known and accepted within the German sediment management market. Therefore the two first harbor projects in Germany have been scientifically supervised.
and documented by the University of Rostock. The main focus was set on the geotechnical characteristics of the dewatered residuals after treatment with the tubes. Of greater interest was the time dependant development of the dry solid content. In the following the two projects and the results of the analysis will be described. Finally the gained insights will be discussed and the project result will be compared.

2. VERDENER SPORTBOOTHAFEN (VERDENER MARINA), VERDEN

The Aller river, the Weser’s largest tributary, is designated as 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. Previous to 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 a 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).

2.1 Project set-up

The project equipment consisted of three main components:

- The dredger with a mixture capacity of approximately 400 m$^3$/h to 450 m$^3$/h.
- The polymer preparation and admixture unit.
- Three dewatering tubes manufactured of polypropylene.

Initially a buffer 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 two different arrangements are schematically shown in Figure 1.

Figure 1. Schematic illustration of the initial project set-up with buffer (left hand side) and final set-up with direct inline polymer injection without buffer (right hand side) (Wilke 2011).
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. By use of a pump sump the filtrate was re-fed into the harbor basin.

2.2 Experimental program and analysis
The filtrate quality was checked concerning the turbidity and suspended solids. Due to the organic content the filtrate was slightly colored. There was no need for establishing a downstream mobile water treatment plant or for prohibiting the direct re-feeding.

The following geotechnical tests were performed for the dewatered material stored within the three tubes:

- Determination of grain-size distribution according to DIN 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 of May and was completed 22nd of July.

2.3 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 was varying 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 depending dry solid content analysis is shown in Figure 2. 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 2. 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.](image-url)
2.4 Discussion

It has to be concluded that the Marina cleaning in Verden was a success. The achieved dry solid contents in such a short period of time are excellent in comparison for example to the time consuming treatment by dredged material disposal sites or drying beds. Furthermore the monitoring for approximately three months showed that by use of 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 comparable 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.

3. HUSUM HARBOUR, HUSUM

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 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. Based on preliminary investigations the sediment was characterized mainly as silt with an ignition loss of approximately 7%.

3.1 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.

3.2 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 15.0m 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).](image)

Due to the greater number of dewatering tubes, not all of them could be scientifically analyzed. 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 again 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 4.

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.

### 3.3 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 to 51.61%.

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. Whereas the highest final value of 13.65 kN/m² was detected at the middle of the lower tube at sampling location 2.
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 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).
3.4 Discussion

The dewatering tube performance and the achieved results convinced the authorities to take a decision: the main section also was executed by the use of the geosynthetic dewatering tube system. However, some phenomena could be observed:

- It seems that the increase of the DS content is not fully completed, even after 6 months.
- The deviations and outliers may be due to the aftermath of the filling operation.
- The undrained vane shear strength variation is great and strongly related to the location. In most cases the shear strength increases towards the bottom of 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.

In contrast to the undrained vane shear strength, there seems to be a stronger link between the tube layer and the achieved dry solid contents:

- The lower tubes exhibit greater DS contents.
- The upper tubes exhibit lower DS contents.

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.

4. 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. The following conclusions are reached for these two projects and the dewatered materials examined over a period of three and nine months:

- The geosynthetic dewatering tube system works well and is an efficient option for the remediation of smaller and bigger sediment volumes.
- The system is gaining more acceptance also in Germany, which is highlighted by an increasing 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 differ related to the project and the location of the tube.
- The curve of the dry solid content development clearly approaches a horizontal asymptote. As the projects are located in quite rainy regions it can be definitely 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.
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 overall summary it can be stated that both projects have to be regarded as great successes and will hopefully increase the further acceptance for the efficient and economic geosynthetic dewatering tube system.

REFERENCES


