IMPROVING THE DEWATERING OF MARINE SEDIMENT USING A COMBINATION OF GEO-TEXTILE AND ELECTROKINETIC TREATMENT

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ABSTRACT

The purpose of this study was to test whether electro-osmosis can be used to increase the effectiveness of dewatering of dredged sediment being drained in geo- textile tubes. The marine sediment used in the study had a high proportion of clay known to be problematic in geo-tube treatment. The laboratory set-ups were performed using sediment-filled sacks (approximately 5-7 liters / sack) sewn from geo-textile (TenCate Geotube® GT500), and plastic columns (approximately 1.6 liters / column) closed at the bottom with geo-textile, both supplied with electrodes for applying direct current. In the sack set-ups, a seven-hour electric treatment led to the same result as the 72-hour control treatment. The volume of the sediment decreased in column set-ups by 32 % due to electric treatment while only a 14 % decrease was obtained in the controls after 189 hours. The water layer on top of the sediment treated with electro-osmosis decreased by up to one-fifth, as compared to the control columns. We can conclude that electro-osmosis is an effective approach to boost the dewatering of the dredged sediment treated in geo-textile tubes. When draining sediment with a high clay content, electric treatment can prevent the formation of a water column on top of the sediment. This in turn accelerates dewatering of the dredged material.

KEYWORDS

Electro-kinetic dewatering, Electro-osmosis, Sediment.

1 INTRODUCTION

Every year a considerable amount of both marine and freshwater sediment has to be removed by dredging for the purpose of maintenance, construction or restoration of ecosystems. Part of the sediments are contaminated and therefore considered waste. In a recent discussion article, Apitz (2010) describes sediment management strategies in terms of waste hierarchy [1]. Policies demand more sustainable sediment management, particularly in the form of waste minimization, re-use and recycling [1].

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Geo-textile tubes and bags have been used for controlled dewatering of slurry waste and contaminated sediment for many years. The dredged sediment is pumped into the tube or bag and the water flows through the geo-textile, while the sediment with possible contaminants stays inside the sack. The application provides a large contact area with the sediment to enable efficient dewatering. Significant reduction in the contained volume (and a comparable gain in solids concentration) in a relatively short period of time is expected and although there can be an initial loss of solids through the geo-textile tubes, this must stop a relatively short period after dewatering begins. Chemical accelerants as well as electro-osmosis have been applied to accelerate the dewatering of sediment and slurry [2].
Electrokinetic geosynthetics (EKG) have been identified as a platform technology, which combines a wide variety of materials, functions and processes to perform such diverse functions as dewatering, strengthening and conditioning in materials such as soils, sludges, slurries, tailings and compost [3]. Dewatering of sewage sludge using EKG together with a belt press succeeded to raise the dry solids content of the dewatered cake from 19 % to > 30 %, which will make the handling of sludge considerably cheaper [4,5]. Also, the EKG application offers potential to dewater sewage lagoons *in situ* [6]. Tuan and Sillanpää (2010) combined polyelectrolyte and freeze/thaw conditioning of sludge into an electro-dewatering process, which significantly reduced dewatering time and increased the dry solid content in the final sludge cake [7].
The aim of the study was to test through laboratory set-ups how much it is possible to increase the effectiveness of dewatering by electro-osmosis when dredged marine sediment with high clay content is being drained in geo-sacks. Electro-osmosis here means the movement of water through the sediment and the textile where the anode is inserted in the sediment slurry and the cathode is applied on the outside of the geo-textile and direct current is connected between them. The geo-sack treatment is known to work well with sandy sediment and organic sludge. The type of marine sediment used in this study contains a high amount of clay that migrates towards the geo-textile, thereby clogging it and quickly resulting in a situation where the water stays on top of the clay and does not come out. We constructed two laboratory set-ups, one in sacks made of geo-textile (three tests) and one in plastic columns with one end closed with geo-textile. Also, chemical flocculant was included in one test.

2 MODELING ELECTRO-OSMOSIS IN GEO-TEXTILE SACKS

2.1 Sediment used for laboratory experiments

Marine sediment was collected in September 2006 by diving from the Baltic Sea off the coast of Helsinki, Finland. The sediment was known to be contaminated by organotin compounds, heavy metals and Polycyclic Aromatic Hydrocarbons (PAHs) – compounds in very low concentration [8]. The sediment was diluted with tap water for the tests.

2.2 Preparation of geo-textile sacks and experimental set up

The experimental set-up consisted of three tests, which lasted from seven to 72 hours. Four sacks were sewn using geo-textile TenCate Geotube® GT500 manufactured by TenCate Europe. This tough netlike textile is made of polypropylene and according to the manufacturer is inert to biological degradation and resistant to naturally encountered chemicals, alkalis, and acids [9]. The size of the sacks was 75 cm x 25 cm and their volume ca 6 L. The sacks were placed in plastic boxes, where silica sand was added as a bottom layer (0.5-1.5 mm) (*See Figure 1*). Out-coming water from the boxes was collected to Erlenmayer flasks through plastic tubes. The anode was constructed from five stainless steel sticks in sequence while the cathode was a net made of steel. The anode was placed inside the sack in the slurry and the cathode in the sand layer under the sack not in direct contact with the textile. The anodes and cathodes were connected to direct current from an electrophoresis power supply (Muuntosähkö Oy, Finland).

The objective of the first tests was to find the best voltage and current settings for electric treatment as well as to test chemicals improving the dewatering. Sediment and water was added in all the sacks (1+1) resulting in a total volume of six liters per sack. Ash was added to the diluted sediment to a final concentration of approximately 0.08 kg L^{-1}, and flocculant chemical (0.1 %) into sediment-ash mixture to reach a final flocculant concentration of 0.017 %. Ash was added in order to improve the formation and stability of flocks. The flocculate chemical was a polymer FLOPAM AN 934 (SNF Finland Oy), which is originally manufactured for water separation. These additives were selected on the basis of previous laboratory scale test, which only selected the best combination of additives for flock formation but did not predict dewatering of the sediment [8]. In the second test, two parts of water and one part of sediment was used (total volume 4 L per sack) and in the third test, the water to sediment ratio was 3:4 and the total volume approximately 4.7 L. Dewatering of diluted sediment in the geo-textile sack experiment was measured gravimetrically at the beginning and at the end of the experiment as well as by measuring the amount of out-coming water (ml).

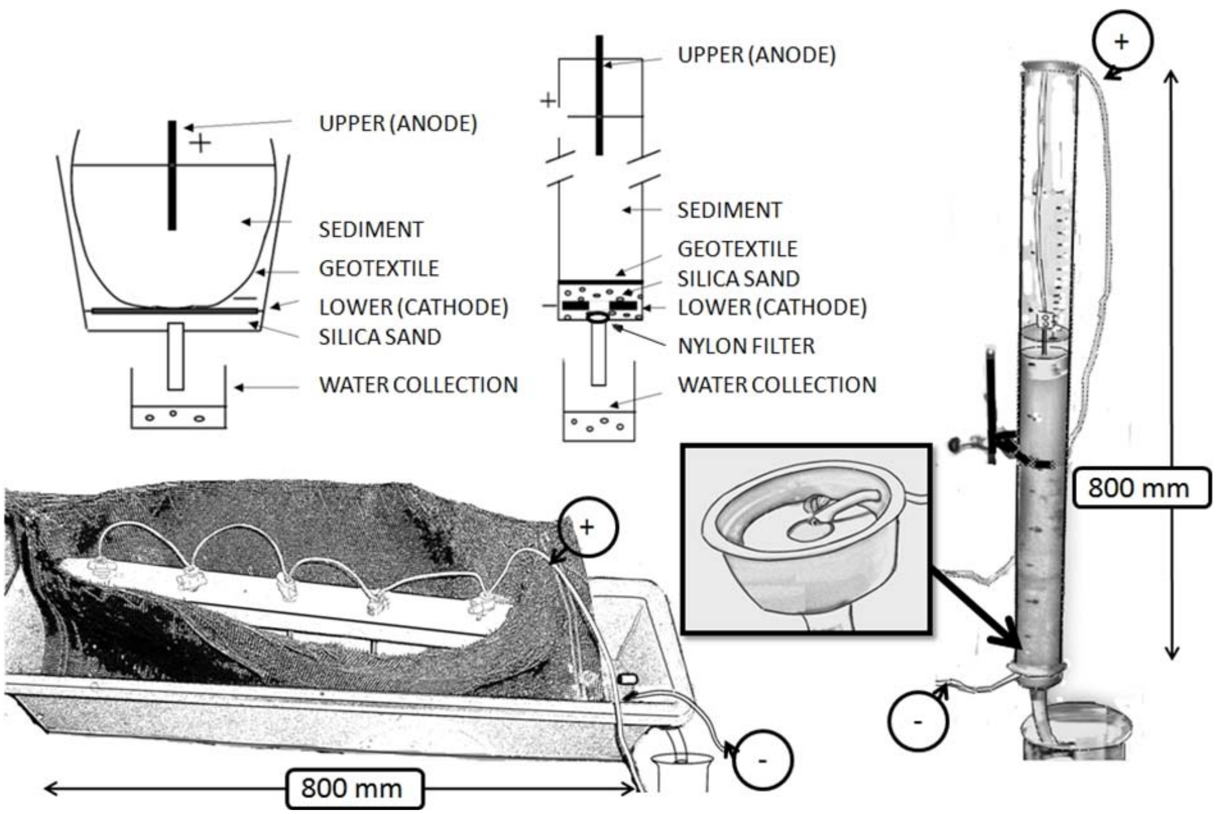

Figure 1. Schematic representation of the geo-textile sack and plastic column constructed for testing electro-osmosis for dewatering of dredged sediment.

2.3 Results and discussion of the geo-textile sack tests

In all the three tests, electricity accelerated the dewatering of the dredged sediment in all four geo-textile sacks (*See Table 1*). Having electricity on for seven hours resulted in 82 – 97 % reduction of the water, which had been added into sacks at the beginning of the test. Without electricity the reduction was from 63 % to 79 % (*See Table 1, tests 2 and 3*). The third test showed that without electricity it took ten times more (72 hours) to have a 40 % reduction of water from the whole mass of the sack content. The addition of ash and chemical flocculant did not improve dewatering and the results even indicated that the additives may have a negative influence when used together with electricity (*See Table 1, test 1*).

The first test revealed that even a voltage of below 20 V and a power of 4-8 W was enough to dry a small mass (4-6 L) quite quickly. From 20 % to 100 % of the full capacity of the power supply (70 V) was used for testing, which resulted in a power input of 4.5 - 173 W. Some heating of the anode was observed during the test, and silica sand was added in between the geo textile and the cathode in order to avoid over-heating of the electrodes. In field applications, a wet sand layer could be a similar solution. At the beginning of every test, the current was relatively low but when water came out of the sacks and the bottom of the sacks, the sand and thereby the cathode got wet, the current increased. In the field scale this is most probably not a problem, because the outsides of the sacks are wet from the start. At the end of the test, drying of the anode was a problem, making the resistance higher and the current weaker.

Table 1: Technical details and results of three geo-textile sack tests.

	TEST 1	*TEST 2*	*TEST 3*	
	Reduction of added water	Reduction of added water / whole mass	Reduction of added water / whole mass (7 h)	Reduction of water from the whole mass (72 h**)**
Sack 1; electricity	80 %	97 % / 45 %	93 % / 41 %	
Sack 2; no electricity	63 %	63 % / 31 %	79 % / 32 %	40 %
Sack 3; electricity	53 %, ash and flocculant	82 % / 39 %	91 % / 39 %	
Sack 4; no electricity	56 %, ash and flocculant	79 % / 37 %	77 % / 31 %	40 %
TEST 1 Duration 25 hours Electricity on for 1 hour (sack 3) and 4 hours (sack 1) 11 – 70 V, 0.4-2.5 A, 4.5-173 W		*TEST 2* Duration 7.5 hours Electricity on for 7.5 hours 16 – 18 V, 0.1 – 0.4 A, 1 – 7 W	*TEST 3* Duration 72 hours Electricity on for 7 hours 18 – 20 V, 0.1 – 0.4 A, 1-9 W	

Manufacturing the geo-textile sacks proved to be challenging. Worse dewatering of sack 3 in the second test could be explained by different stitching, causing slower drainage of water, thus leading to dryness of the cathode and higher resistance. This was proven by observing the power values during the test. In the third test, uneven permeability was noticed in two of the control sacks proved by analyzing the concentration of solids from the out-coming water (approximately 12 g L^{-1}) and comparing it to two other sacks (approximately 6 g L^{-1}). In addition, the experimental set-up had some practical challenges. There was some evaporation from the plastic boxes where the sacks were standing. During the second and third test, approximately 300 g of water evaporated from sacks treated with electricity while without electricity the corresponding quantity was 200 g. This has been taken into account when estimating the reduction of water from the whole mass. These practical challenges did not change the unambiguous result that electricity accelerates dewatering of the sediment.

3 MODELING ELECTRO-OSMOSIS IN PLASTIC COLUMNS

3.1 Preparation of plastic columns and experimental set up

The objective of the column test was to determine whether the distance between electrodes has an effect on dewatering of the sediment. In addition, the test made it possible to model the sedimentation phenomenon where the sediment clogs the geo-textile. A water layer above the sediment results in a lack of contact between the water and the geo-textile. Another goal of this test was to estimate the sedimentation rate per cm^2 of the geo-textile.
Six plastic columns (45 x 800 mm) with a geo-textile component, silica sand and anode and cathode were constructed (*See Figure 1*). The anode was a steel rod, which was inserted into the slurry inside the column, while the cathode was a thin steel plate placed in the water outside the column with contact to the geo-textile at the bottom of the column (*see Figure 1*). Components were glued together carefully to ensure that the surface areas (15.90 cm^2) of the geo-textile components would be as uniform as possible and thus the results comparable. The water which was filtered through the geo-textile, silica sand and nylon filter (made of nylon pantyhose material) was collected in Erlenmayer flasks using plastic tubing. The connections and permeability of the geo-textile components were tested before the columns were used.
Water plus sediment slurry was added to every column resulting in a total volume of approximately 1.6 L. The density of the mixture of sediment and water was approximately 1200 g L^{-1}. Electric was turned on in columns 1-3 and columns 4-6 were controls with no electricity. The anodes were lowered as the volume of the slurry decreased. The test lasted for 7 days (189 hours) for control columns while in columns 1-3 electricity was on during the working days, altogether for 37 hours (6 x 4-8 hours with breaks of 15-19 hours) (*see Figure 2*).

3.2 The measured parameters

In the column experiment, the speed of dewatering was observed by measuring the amount of out-coming water and measuring how much the liquid surface moved downwards in the plastic columns during the experiment (mm). During the experiment, sediment and water separated and a clear water column appeared above the sediment. The height of this column was measured starting as it became clearly visible three days from the beginning of the experiment, when electricity had been turned on for 18 hours.
At the end of the column experiment, the water content of the sediment was measured form the top, middle and bottom of the columns by determining dry weight. Using these values, the effect

of electricity on the formation of the gradient of the water content was calculated. The dry weight was measured from homogenized samples by drying 1 g of a sample for 24 hours at 105°C. The density of the sediment at the end of the column experiment was calculated using humidity percentages and by estimating the water content and density of sediment mass at the beginning of the experiment.

pH values were measured from columns using a portable IQ150 pH meter (IQ Scientific Instruments). At the end of the experiment, pH was measured from samples taken from different levels in the column. The solids (mg L^{-1}) of out-coming water were measured by centrifuging water samples (50 ml) in Kimax tubes for 15 minutes (2500 rpm).

3.3 Results and discussion of the plastic column tests

The results of plastic column tests were in agreement with the results of the tests involving geo-textile sacks. In columns that were treated with electricity, the volume of the mass decreased by 32 % during the 189 hours experiment with 37 hours of electric treatment. In the control columns, only a 14 % decline was achieved in 189 hours. Estimation based on these results would predict that the same situation of dewatering could be reached in 470 hours in columns without electricity although the evaporation could of course accelerate the reduction of water. Typically electro-osmotic dewatering of clay soils is of the order of 1-4 orders of magnitude faster than hydraulic dewatering [5].

On average, 400 ml of water was collected from plastic tubes with electric treatment, half of which when electricity had been on for 13 hours (*See Figure 2*). In order to quantify the effect of electricity, we calculated the flow through the geo-textile disks at the bottom of the cylinders with and without electricity. When electricity was used, the speed of the water passage was from 17 ml h^{-1} in the beginning to 6 ml h^{-1} at the end of the experiment for the 15.9 cm^2 geo-textile disc. This estimation is calculated by dividing the volume of out-coming water by the hours electricity had been on. Without electricity the speed of the water passage was from 4 to 0.5 ml h^{-1} for the 15.9 cm^2 geo-textile disc (*see Figure 2*). The sediment condensed when electricity was used, which was proven by the observation that at the end of the experiment, in lower parts of columns 1-3 the humidity percentage was slightly lower and the density of the mass higher than in columns 4-6. For practical purposes the most important target is to decrease the water contents of the sediment and make it transportable or usable in some other way in an as short time as possible. So achieving efficient condensation of the sediment is a promising phenomenon. Also, during the electricity breaks, water came out better from the columns with no electric treatment. The speed of the water passage during the breaks was from 0.3 to 0.5 ml h^{-1} with electricity and from 0.4 to 1 ml h^{-1} without electricity.

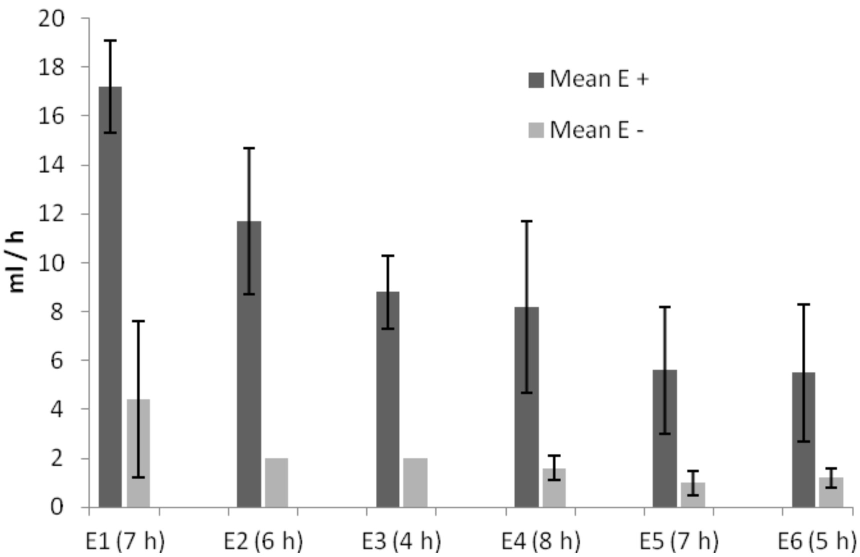

Figure 2. Means and standard deviations of results (ml / h) from three plastic columns with electricity and three without electricity. Electricity (approximately 163 V) was on from 4 to 8 hours.

Another clear result of the column test was that the water layer above the sediment was considerably smaller in columns with electricity than in columns without electricity. At the point where the test had been run for 95 hours and electricity had been on for 27 hours, the volume of the water column was approximately 37 ml (height 22 mm) in columns 1-3, while in columns 4-6 without electricity the volume of the water column was 183 ml (height 110 mm).

Marine sediment with high clay content can be a problem in geo-textile sack treatment, when a water layer appears above the sediment, resulting in slower dewatering. The geo-textile tube performance has to be evaluated before choosing the application. Different tests, for example the hanging bag test (HBT) and semi-performance test, have been reviewed [2]. However, sampling of the sediment for the hanging bag test is challenging. For example, in one field case in Finland, where marine sediment from a 1200 m^2 area was dredged (approximately 700 m^3), dewatering of the sediment in geo-sack was slower than expected based on the results of the hanging bag test. The reason for that was that the water, clay and humus content of the dredged sediment placed in the geo-textile tubes was higher than in a test sample [9].

During the test, the volume of the sediment decreased due to condensation, the anodes were lowered and the voltage per centimeter rose. The current varied from 10 to 50 mA and declined towards the end of the test because the sediment became dry and a pH gradient was formed. An electrolysis reaction at the electrodes causes pH changes when oxidation of water occurs at the anode, generating hydrogen ions. In contrast, reduction of water occurs at the cathode and generates hydroxyl ions [10]. At the beginning of the test, the pH of the water-sediment mixture ranged from 4.0 to 5.1. After 75 hours (electricity turned on for 22 hours), the pH values for the water column were 3.1 (+/- 0.04) (columns 1-3) and 4.9 (+/- 0.5) (columns 4-6) and the respective pH values for the out-coming water were 12.2 (+/- 0.02) and 7.4 (+/- 0.14). One option to alleviate the pH gradient is to cycle the alkaline water into the sediment and thus neutralize the pH. The benefit of this is, however, questionable because the ultimate goal is to dry the mass, not to wet it. One option could be a neutralizing chemical but the price of this kind of application is

high in the field scale. The aim is that the application is simple and cheap. If the sediment is contaminated with metals, changes in pH may cause a risk, but this aspect was not dealt with in this study.
In the tests the anode was corroded a little. The material of the anode is essential, especially when using more current. The ideal material should be resistant to oxidization or be easily replaceable. When considering further development of the electrokinetic-enhanced geotube dewatering system, the material of the electrodes should be selected with care. Geosynthetic electrodes offer benefits, including corrosion durability [3]. A metallic cathode net could be embedded in sand under the sack. This system could be a rather simple and moderately priced method to speed up the process of draining dredged sediments.

4 CONCLUSIONS

We can conclude that it is possible to increase the effectiveness of dewatering by electro-osmosis when dredged marine sediment with high clay content is being drained in geo-sacks. In addition, electric treatment can prevent the formation of a water column on the top of the sediment and might cause condensation of the sediment, which are both desired effects. High pH may cause problems if treated sediment is contaminated by metals, but this issue needs further studies. Plastic columns with geo-textile component proved out to be useful test equipment for testing sediment. Results presented in this paper are very promising and should be tested in the field case.

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