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Effect of polyaniline coated galvanized steel electrodes on electrokinetic sedimentation of dredged mud slurries

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Complete List of Authors:	Malekzadeh, Mona; JAMES COOK UNIVERSITY, School of Engineering & Physical Sciences Sivakugan, Nagaratnam; James Cook University, Kazum, Oluwole; James Cook University Faculty of Science and Engineering, Chemical engineering Mathan, Bobby; James Cook University, College of Science, Technology & Engineering
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Title: *Effect of polyaniline coated galvanized steel electrodes on electrokinetic sedimentation of dredged mud slurries*

Malekzadeh M.

PhD Candidate, MSc, BSc in Civil Engineering, School of Engineering & Physical Sciences, James Cook University, Townsville, QLD. 4811, Australia; PH +61 7 478 15685; email: mona.malekzadeh@my.jcu.edu.au

Sivakugan N.

Associate Professor, PhD, RPEQ, FASCE, Discipline of Civil Engineering School of Engineering & Physical Sciences, James Cook University, Townsville, QLD. 4811, Australia; PH +61 7 478 14431; email: siva.sivakugan@jcu.edu.au

Kazum O.

Discipline of Chemical Engineering, School of Engineering Physical Sciences, James Cook University, Townsville, Queensland 4811, Australia PH +61 7 4781 5080; email: oluwole.kazum@my.jcu.edu.au

Mathan B.

Discipline of Chemical Engineering, School of Engineering Physical Sciences, James Cook University, Townsville, Queensland 4811, Australia PH +61 7 4781 5080; email: bobby.mathan@jcu.edu.au

Abstract:

An experimental study on electrokinetic improvement of dredged marine sediments to accelerate their sedimentation for land reclamation purposes is presented. Electrokinetic stabilization is currently used to improve soils, however, its use on soils with marine sediments with low permeability is still questionable due to the deterioration of anodes caused by electrolysis reaction. A number of traditional methods are employed in literature to reduce the corrosion degradation of metals such as painting, galvanizing and conversion coating. Conducting polymers such as polyaniline is of engineering interest due to its properties such as ease of preparation and its high environmental stability in protecting metals from corrosion. For this purpose, the anodes used in electrokinetic testing cell herein were coated with polyaniline to investigate the effect on electrokinetic stabilization of the dredged mud. Two series of experiments were performed using a polyaniline coated galvanized steel anode, and two series of experiments with non-coated galvanized steel anodes as a control were also carried out. Depending on the applied voltage, the settlement and electroosmotic permeability of the dredged mud varied during the process. Polyaniline coating increased the power consumption during the electrokinetic stabilization compared to the case where the same electric potential is applied using the uncoated electrodes. However, when 5 V electric potential is applied to the soil through the polyaniline coated anode, its settlement and electroosmotic permeability are equivalent to what was observed with 30 V electric potential applied through the non-coated anode, with 3 times less energy consumption.

Keywords: Polyaniline coating; soil improvement; galvanized steel; anode; dredged marine sediments;

1

2 **Introduction**

3 Dredged marine sediments are characterized by their low permeability which results in long
4 durations of settlement. To accelerate the sedimentation and consolidation of the dredged
5 sediments, electrokinetic stabilization seems to be an effective method. Electrokinetic
6 stabilization was first trialled by Casagrande (1949) to improve the properties of soils. However,
7 a specific design standard has not yet been developed, due to the complex electrochemical
8 reactions that happen in the soil during electrokinetic stabilization and parameters that affect the
9 process such as pH, type of minerals in the soil, salt content and soil resistivity. The effect of
10 these parameters and the chemical reactions in the soil cause permanent changes in the soil and
11 result in an increase in strength properties of soils (e.g. Micic et al. 2001; Rittirong et al. 2008).
12 Electrical field parameters such as the type of electrodes have significant effect on the efficiency
13 of the electrokinetic stabilization. The type of the electrode affects the electrokinetic stabilization
14 based on their reaction that takes place with the soil minerals and loss of voltage within the soil
15 (Mohamedelhassan and Shang 2001). Metal electrodes are susceptible to corrosion due to the
16 acidity of the environment near the anode caused by the electrolysis reaction at anode. A number
17 of traditional methods are employed to reduce the corrosion degradation of metals such as
18 painting, galvanizing and conversion coating. Recent years have seen a rise of interest in using
19 conducting polymers for the corrosion protection of metals. This is due to their attractive
20 properties such as corrosion inhibition, ease of preparation and high environmental stability.
21 Galvanized steel is one of the most common, easily accessible and inexpensive metals for use in
22 electrokinetic stabilization. However, it is one of the metals that is more easily corroded.
23 Therefore, in this study a conductive polymer referred to as Polyaniline is Galvano-statically

coated on galvanized steel and the effect of the coating on electrokinetic sedimentation properties of the dredged mud is investigated.

Experimental study:

Laboratory Set-up

An electrokinetic testing cell shown in Figure 1 is used to investigate the settling behaviour of the dredged sediments during electrokinetic stabilization. The following aspects were considered in selecting this set-up.

- a) *Settlement columns*: settlement columns were chosen to monitor the changes of interface height with time, which shows the sedimentation of the dredged mud.
- b) *Placement of anode at the bottom*: The flow of water is mostly from the anode to the cathode due to electroosmosis, and placing the anode at the bottom attracts the soil particles toward the bottom of the column by electrophoresis and increases the rate of sedimentation as presented by Malekzadeh and Sivakugan (2015).
- c) *An impervious base*: Having an impervious base results in accumulation of all of the drained water on top of the sediment, from which it can be collected. According to Malekzadeh and Sivakugan (2015) providing a double drain condition increases the soil resistivity due to the generation of the cracks near the anode which results in an increase in power consumption and therefore it is not suggested.
- d) *Using filter papers*: Filter papers are placed between sediment and electrodes for water filtration purposes.

Four Perspex settlement columns with an inner diameter of 90 mm, height of 500 mm and 3 mm wall thickness were used. Two electrodes made of galvanized steel with the size of 88 mm are placed horizontally at the bottom and the top of the settlement column. The top electrode, the

cathode, is removable for ease of sample preparation. The top electrode is placed in contact with the sediment and will therefore move as the interface height changes.

Figure 1

Material properties

Soil:

Remoulded dredged mud with specific gravity of 2.61, which was measured using AS 1289.3.5.1, is used herein. The samples of dredged mud are taken from the land reclamation area at the port of Brisbane, Australia. To simulate the consistency of the slurry as it is pumped into the paddocks, the moisture content of the sediment was measured and brought up to 250% by adding more distilled water. Distilled water added to keep the concentration of salt similar to the initial condition where the samples of dredged mud is received from the port. To ensure the homogeneity of the samples, a mixer was used to mix the water with the sediments properly and the slurry was then left for 24 hours before pouring into the settlement column. The liquid limit and plastic limit of the dredged mud were obtained according to AS 1289.3.9.1 and AS 1289.3.2.1, respectively. The plasticity index of the dredged mud was 52% whilst the liquid limit was 92%. Therefore based on United States soil Classification System, the sediment is classified as clay of high plasticity (CH). The linear shrinkage of the soil was measured according to AS 1289.3.4.1 and found to be 33%.

Materials:

Galvanized steel: Galvanized steel was used in this study, due to its low cost and availability. Galvanized steel is typically steel that is coated with a layer of zinc oxide to reduce its rate of corrosion.

Galvanized steel sheet with thickness of 2mm: Galvanized steel sheet with thickness of 2 mm was cut into circular plates and perforated for better drainage from the top to be used as the cathode.

Galvanized steel sheet with thickness of 5 mm: To reduce the time at which the anode corrodes, which interrupts the current flow through the soil, a thicker sheet of galvanized steel was used as an anode.

Polyaniline coating: Polyaniline coating is a widely used conductive polymer that is used to increase the aqueous corrosion resistance of metals (Santos et al. 1998). During electrokinetic sedimentation of soils, the pH near the anode reduces due to the electrolysis and this results in corrosion of the anode and disruption of the electrokinetic process. Polyaniline is obtained by electrochemical oxidation and polymerization of aniline (Skotheim and Reynolds 2007) which has unique properties such as being a low cost monomer, high electrochemical activity, stability, and optical activity (Gvozdenovic et al. 2012). As polyaniline is very effective in reducing the corrosion especially in an acidic environment (MacDiarmid and Ahmad 1997), it was chosen as the coating material.

Methodology:

Anode modification:

Polyaniline coated anode: The anode was made, using a 5mm thick galvanized steel sheet with diameter of 900 mm that is coated with Polyaniline to reduce its corrosion rate. Polyaniline coating is usually done by methods such as direct deposition from solvents, electrochemical synthesis, and coating with various commercial coatings such as epoxy, polyester, and acrylic (Gvozdenovic et al. 2012). In this study, the coatings were performed by electrochemical synthesis. Galvanized steel is steel that is coated with a layer of zinc oxide, forming the bond

93 between polyaniline and the layer of zinc oxide was challenging and the first trial coating was
94 not successful. For this reason, samples were ground with SiC papers up to 1200 grit, followed
95 by ultrasonic cleaning in acetone and ethanol to eliminate any dirt prior to coating. The synthesis
96 of polyaniline coating on the steel was done by the Galvano-static technique using a Potentiostat
97 (Model: VersaSTAT3 PAR) with a three-electrode cell, Steel is used as a working electrode,
98 silver/silver-chloride is used as a reference electrode, and graphite as a counter electrode, and the
99 coating bath was an electrolyte containing 0.3 M aniline and 0.1 M aqueous sodium salicylate
100 solution. Each coating was done under a high current density of 20 mA.cm^{-2} , applied for 10 min.
101 For more detail information on how the polyaniline coating is done refer to Kazum and Mathan
102 (2013).

103 **General procedure:**

104 When the anodes had been coated, they were attached to the plain Perspex sheet that is used as
105 the impervious base at the bottom of the settlement column. To allow for the wire that is
106 connected to the anode, a hole with diameter of 6 mm was drilled through at the centre of the
107 base. The hole was later sealed with silicon once the wire is fed through. The Perspex base was
108 then screwed to the rim of the settlement column after placing a filter paper on top of the anode.
109 The soil slurry was then poured into the column at once using a funnel assuming there would be
110 no lag time. The cathode is then placed on top of the soil specimen after placing a filter paper.
111 The wires are then connected to the poles, positive pole for anode, negative pole for cathode, and
112 the DC supply is turned on, applying a constant voltage of 30 V and the changes of electric
113 current and interface height with time is monitored.

114 **Results and discussion:**

115 **Variation of current density with time**

The constant electric potential of 30 V or 5 V were applied to the dredged mud. When the electric potential was applied, the electric current was monitored for all cases until the tests were completed. Because electric current varied similarly in 30V coated and 30V non-coated tests, the fitting curves coincide at t_{opt} (Figure 2). Referring to the figure, when 5 V electric potential was applied to the soil through the coated anode, the pattern of changes in electric current with time was similar to when 30 V was applied through the coated anodes. This shows that the polyaniline coating increased the efficiency of the method by reducing the soil resistivity. However, this only happened when low voltage of 5 V was applied. In case where electric potential of 30 V was applied through the coated anode, the soil resistivity was higher than the case of non-coated anode. This shows that the polyaniline coating was disintegrated at voltage of 30 V, resulting in higher resistivity and power consumption in comparison with non-coated anode.

Figure 2

As electric current and resistivity of the soil change with time and as soil particles settle, the density of the soil changes, and as a result the settling velocity varies. The variation of settling velocity with changes of electric current is given in Figure 3. The settling velocity of the soil is shown to be at its maximum when the electric current is the maximum. The polynomial regressions to the measured settling velocities with respect to changes of electric current with application of 5 V and 30 V electric potential through coated and non-coated electrodes, are defined as:

When 30 V electric potential is applied through coated anode:

$$V_s = -32.45 I^2 + 19.28 I + 0.53 \quad (1)$$

When 5 V electric potential is applied through coated anode

$$V_s = -31.55 I^2 + 18.56 I + 0.564 \tag{2}$$

When 30 V electric potential is applied through non-coated anode

$$V_s = -27.14 I^2 + 5.22 I + 0.29 \tag{3}$$

When 30 V electric potential is applied through non-coated anode

$$V_s = -4.09 I^2 + 5.79 I + 1.07 \tag{4}$$

where V_s is the settling velocity in mm/hr and I is the electric current in Amps. These regression equations are valid for electric current ranging from 0 to 1 amp showing that the electric current of the soil does not exceed 1 amp when 30 V electric potential is applied. The settling velocity based on electric current gives an information about soil resistivity. Since soil resistivity is a function of chemical changes in the soil, therefore it is necessary to investigate the relationship between settling velocity based on application of electric current. The maximum settling velocity is obtained at electric current of 0.3 amps in case of coated anode, and 0.6 amps in case of 30 V non-coated electrode, and less than 0.1 amps for when 5 V electric potential is applied.

Figure 3

The maximum electric current at optimum time and maximum electric current at maximum settling velocity that is obtained for each case is given in Table 1. When 30 V is applied through the non-coated anode, the maximum electric current is reached as soon as 8 hours. Whereas, if the anode is not coated, the maximum electric current with applying the same voltage is reached in 18 hours. When electric potential of 5 V is applied through the coated anode, same amount of time is required to reach the maximum electric current. This shows that polyaniline coating

improved the electrokinetic stabilization of the dredged mud if 5 V electric potential is applied and resulted in lower power consumption and higher electrokinetic efficiency.

Settling velocity is based on the hydraulic and electroosmotic permeability of the soil. Therefore, the relationship between electric current and settling velocity given in this section shows that the highest hydraulic and electroosmotic permeability was achieved at electric current of 0.3 amps when anodes are coated. Whereas, the ultimate current for non-coated anodes is twice the coated anode for application of 30 V electric potential and less than half for application of 5 V electric potential. Therefore, application of constant $I_{v(max)}$ is suggested electric current to obtain the maximum possible settlement. Use of $I_{v(max)}$ as the design electric current result in lowest power consumption and maximum settlement.

Table 1

Electrokinetic sedimentation

The changes of interface height with time is shown in Figure 4. It is shown that if 5 V electric potential is applied through coated anode the sedimentation behaviour of the soil is similar to when 30 V constant electric potential is applied. Application of 30 V electric potential through coated anode did not significantly change the final settlement of the soil, and only 11% increase in final settlement of the dredged mud is observed. This is due to the disintegration of the polyaniline coating at higher voltage of 30 V, and is attributed to the unknown chemical reactions resulting from the interaction between polyaniline coating and dredged mud particles, or changes in resistivity of the anode by applying the polyaniline coating. However, when 5 V electric potential is applied through polyaniline coated anode, the final settlement of the dredged mud increased to 73% of the final settlement of the dredged mud in case of non-coated anode.

The logarithmic regression that is the best fit of the experimental data shows the settlement of the dredged mud at any time during electrokinetic stabilization given as:

When 5 V electric potential is applied through coated anode:

$$S = -47.38\ln(t) + 472.84 \quad (5)$$

When 5 V electric potential is applied through non-coated anode

$$S = -31.521\ln(t) + 475.03 \quad (6)$$

When 30 V electric potential is applied through coated anode

$$S = -45.1\ln(t) - 463.69 \quad (7)$$

When 30 V electric potential is applied through non-coated anode

$$S = -38.37\ln(t) - 438.61 \quad (8)$$

where S is the settlement of the soil with time and t is the time interval in hours. These correlations are true for the dredged mud with the presented initial state and under the given laboratory condition.

Figure 4

Electrokinetic sedimentation coefficient

The electrokinetic sedimentation coefficient is the slope of the porosity and settling velocity of the slurries. The sedimentation coefficient is related to the process of hindered settling prior to consolidation and it is similar to the coefficient of consolidation during the process of consolidation. When slurry settles, concentration of solids increases with time. As a result, the porosity and the settling velocity of the particles reduces (Mohamedelhasan and Shang 2001).

206 According to Zaki and Richardson (1954) the velocity of suspension V (m/s) depends on porosity
 207 (n) and coefficient of sedimentation (r):

$$208 \quad r = \log_n \left(\frac{U}{V} \right) \quad (9)$$

209 where U is the particle settling velocity (m/s):

$$210 \quad U = \frac{g(\rho_s - \rho_f) d^2}{18 \mu} \quad (10)$$

211 where g is gravitational acceleration (m/s^2), ρ_s and ρ_f are density of solid and fluid respectively
 212 (kg/m^3), d is diameter of particles (m), and μ is the viscosity of fluid (N.s/m^2). The coefficient of
 213 sedimentation can be determined from the plot of settling velocity and porosity. In this study the
 214 settling velocity and the porosity is determined using following equations:

$$215 \quad n = \left(\frac{e}{1+e} \right) \times 100 \quad (11)$$

216 where e is the void ratio, and n is the porosity in percent. The settling velocity (mm/hr) of the
 217 slurry based on changes of interface height is determined from:

$$218 \quad V_s = \frac{\Delta H}{\Delta t} \quad (12)$$

219 where ΔH is the changes of interface height in (mm) within time interval of Δt (hr).

220 The variation of coefficient of sedimentation versus porosity is shown in figure 5. The settling
 221 velocity increases as porosity increases up to 81% after which it reduces. The experiment starts
 222 initially with porosity of 86% which gradually reduces as sediment settles. In case of 5 V non-
 223 coated anode, the settling velocity did not change significantly. However, in case of 30 V non-
 224 coated, the settling velocity increases to a peak of 84% after which, it reduces progressively to a
 225 final porosity of 77%. Both cases of coated anodes follow a similar pattern. In both cases, the

226 settling velocity starts at a relatively slow rate and increases progressively up to a maximum
227 velocity, at porosity of 82%, then it reduces gradually reaching a final porosity of 74%.

228 The sedimentation coefficient increases when properties such as clay content of the soil increases
229 (Shang 1997). The polyaniline contributes to changes in the properties of the dredged mud
230 through unknown chemical reactions which result in better electrokinetic settlement and
231 efficiency. The coefficient of electrokinetic sedimentation is calculated from the left hand side of
232 the slope of the settling velocity versus porosity. The left side of the graph is related to the initial
233 peak of the electric current, and first half of the settlement before consolidation, and the right
234 hand side of the graph is considered as consolidation stage. Therefore, the coefficient of
235 sedimentation is determined using the left hand side of the settling velocity versus porosity plot.
236 The coefficient of sedimentation is 0.46 mm/hr, 0.98 mm/hr, 0.11 mm/hr, and 0.14 mm/hr for 5
237 V non-coated anode, 30 V non-coated anode, 5 V coated anode, and 30 V coated anode,
238 respectively.

239 This shows that for coated anodes, the increase in voltage does not significantly change the
240 settling velocity of the dredged mud. The electrokinetic sedimentation depends on the intrinsic
241 properties of the clay and current density. The results reported in this study are in agreement with
242 the findings of Shang (1997).

243 Figure 5

244

245 Electroosmotic permeability parameters:

246 The soil settling velocity is based on electroosmotic permeability of the soil, and the
247 effectiveness of the electrokinetic dewatering depends on electroosmotic permeability k_e .

248 Electroosmotic permeability is measured using the equation given by Mitchell (1993):

$$q_{eo} = k_e A \frac{j}{\sigma} \quad (13)$$

where q_{eo} is the flow rate of water (m^3/s), k_e is electroosmotic permeability $\text{m}^2/(\text{s.V})$, A is cross-sectional area between electrodes, j is current density in A/m^2 , and σ is the electrical conductivity of the dredged mud slurry (S/m).

As dredged mud slurry settles, the electroosmotic flow reduces with time. The flow rate of water (q_{eo}) that is induced by application of electric current is measured using the volume of drained water within the time interval when interface height changes. Figure 6 shows the changes of electroosmotic permeability with void ratio. The electroosmotic permeability of the dredged mud reduced with reduction of void ratio. The responses of dredged mud to 30 V electric potential that was applied through coated and non-coated anodes were similar. Therefore, their fitting curves are nearly coincident. According to Malekzadeh and Sivakugan (2016), the electroosmotic permeability parameter which is assumed to be dependent on changes of interface height and index properties of the soil is given as:

$$k_e = C^* e^{D^*} \quad (14)$$

where C^* and D^* are electroosmotic permeability parameters and e is void ratio. According to this equation the electroosmotic permeability parameters derived from the performed experiments are as follows:

$$5 \text{ volt non-coated anode: } C^* = 2 \times 10^{-6}, D^* = 2.45 \quad (15)$$

$$30 \text{ volt non-coated anode: } C^* = 7 \times 10^{-6}, D^* = 2.74 \quad (16)$$

$$5 \text{ volt coated anode: } C^* = 3 \times 10^{-5}, D^* = 1.77 \quad (17)$$

$$30 \text{ volt coated anode: } C^* = 7 \times 10^{-6}, D^* = 2.74 \quad (18)$$

Figure 6

Power consumption:

The power consumption in this study is based on two variables. One is the electric current which changes with changes of soil resistivity and time and the other variable is the distance between electrodes, since the cathode moves downward with as interface height changes. Therefore, the following equation is used to determine the consumption of energy.

$$P = \frac{dl}{dt} \times \frac{V}{A} \times \Delta t \tag{19}$$

where P is the power consumption (W.s/m^3) to settle the volume of sediments noted as dl (changes in distance between electrodes), with a constant applied voltage of V (Volts), which generates an electric current difference of dl (Amps) within a time interval of Δt in hours through cross sectional area A (m^2).

The energy consumption for treating 1 cubic meter of dredged mud when constant electric potential of 5 V and 30 V electric potential is applied to the soil through coated and non-coated anodes is shown in Table 2. The consumption of energy when a non-coated anode is used with a voltage of 5 V is 1.97 kWh/m^3 which is very low in comparison with the other cases, however, the percent settlement is relatively lower than other cases too. When 5 V electric potential is applied to the dredged mud through the coated anode the power consumption increases 1.8 times the case of non-coated anode. However, the coating increases the settlement up to 9.8 times. The power consumption increase when the anode is coated with polyaniline. This is attributed to the

lower conductivity of polyaniline coating in comparison with the non-coated anode. The choice of whether to apply the polyaniline coating needs to be based on the budget and timeline of the project. The coated anode with application of 5 V constant electric potential is suggested as an effective anode for maximum electrokinetic efficiency.

Table 2

Conclusion:

This study investigated the effect of polyaniline coating on the electrokinetic dewatering and sedimentation of dredged sediments through comparisons of coefficient of sedimentation, electroosmotic permeability, and changes in electric current which is an indication of soil resistivity, and power consumption. The dredged marine sediments used here were taken from the reclamation site in the port of Brisbane. The following conclusions can be drawn:

- The application of 5 V electric potential to dredged sediments using a coated anode induces a similar settling behaviour to applying 30 V of electric potential through either coated or non-coated anodes.
- For the cases of; 30V applied through a coated and non-coated anode, and 5V applied through a coated anode, the variation of electric current with time, electroosmotic permeability, settlement, and sedimentation coefficient were all similar. In contrast, when 5 V electric potential is applied through the non-coated anode, the power consumption, settlement, electroosmotic permeability and sedimentation coefficient are noticeably lower when compared with all three of the other cases.
- It is shown that applying a layer of coating on the anode increases the power consumption considerably, due to its lower conductivity in comparison with non-coated

316 metal. However, it increases the settlement by up to two times that for the non-coated
317 anode. This difference in settlement is achieved specifically when 5 V electric potential is
318 applied, however this improvement is not reproduced 30 V is applied and results for
319 coated and uncoated anodes are compared. In that case, the power consumption is almost
320 2 times higher with the coated anode, whereas the settlement is not significantly changed
321 and increases only 11% when compared to the non-coated anode.

322 Based on this study, the application of 5 V electric potential with a coated anode would appear to
323 offer noticeable advantages, however the decision to use this method should be made with
324 consideration of the specific project features, including available budget and timeline.

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References:

- Casagrande, I. 1949. Electro-Osmosis in Soils. *Géotechnique*, 1(3), pp.159-177.
- Gvozdenović, M., Jugović, B., Stevanović, J., Grgur, B., Trišović, T. and Jugović, Z. 2011. Electrochemical synthesis and corrosion behavior of polyaniline-benzoate coating on copper. *Synthetic Metals*, 161(13-14), pp.1313-1318.
- Kazum, O. and Kannan, M. 2013. Galvano-static polymerisation of aniline on steel: Improving the coating performance in chloride-containing environment. *Synthetic Metals*, 180, pp.54-58.
- MacDiarmid, A. G. and Ahmad, N. 1997. Prevention of corrosion with polyaniline: Google Patents.
- Malekzadeh and Sivakugan N. 2016. Intermittent electro-consolidation of dredged sediments. Manuscript submitted for publication.
- Malekzadeh M. and Sivakugan N. 2015. Effect of electrode placement on electrokinetic settlement. Manuscript submitted for publication.
- Micic, S., Shang, J., Lo, K., Lee, Y. and Lee, S. 2001. Electrokinetic strengthening of a marine sediment using intermittent current. *Canadian geotechnical journal*, 38(2), pp.287-302.
- Mitchell, J. 1993. *Fundamentals of soil behaviour*. New York: John Wiley & Sons.
- Mohamedelhasan, E. and Shang, J. 2001. Effects of electrode materials and current intermittence in electro-osmosis. *Proceedings of the ICE - Ground Improvement*, 5(1), pp.3-11.

Rittirong, A., Shang, J., Mohamedelhassan, E., Ismail, M. and Randolph, M. 2008. Effects of Electrode Configuration on Electrokinetic Stabilization for Caisson Anchors in Calcareous Sand. J. Geotech. Geoenviron. Eng., 134(3), pp.352-365.

Santos, J., Mattoso, L. and Motheo, A. 1998. Investigation of corrosion protection of steel by polyaniline films. *Electrochimica Acta*, 43(3-4), pp.309-313.

Shang, J. 1997. Electrokinetic dewatering of clay slurries as engineered soil covers. *Canadian Geotechnical Journal*, 34(1), pp.78-86.

Skotheim, T. and Reynolds, J. 2007. *Handbook of conducting polymers*. Boca Raton, Fla.: CRC.

Draft

List of Figures:

Figure 1. The electrokinetic cell used in this study

Figure 2. Variation of electric current with time during electrokinetic stabilization of dredged mud slurry

Figure 3. Variation of electric current with settling velocity during electrokinetic stabilization of dredged mud slurry

Figure 4. Changes of settlement versus time

Figure 5. Variation of settling velocity with porosity

Figure 6. Electroosmotic permeability versus void ratio

List of tables:

Table 1. Optimum time at which maximum electric current occurs

Table 2. Power consumption and percent settlement

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Table 1. Optimum time at which maximum electric current occurs

Electrode condition (anode)	V (volts)	Optimum time t_{opt} (Hours)	I_{max} Maximum electric current (Amps)	$I_{V_s(max)}$ Electric current at maximum V_s (Amps)
Non-coated	5.00	90	0.20	<0.1
Coated	5.00	18	0.52	0.3
Non-coated	30.00	8	0.92	0.6
Coated	30.00	18	0.56	0.3

Draft

Table 2. Power consumption and percent settlement

Electrode condition (anode)	Energy consumption per 1 m ³ of dredged mud (kWh/m ³)	V (volts)	% settlement ($\Delta H/H_i$)*100
Non-coated	1.97	5.00	28.75
Coated	19.34	5.00	50.00
Non-coated	71.88	30.00	42.50
Coated	112.73	30.00	47.50

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Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6