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New generation of Electrically Conductive Vertical Drains for treatment of Singapore waste materials

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ABSTRACT: Waste materials in Singapore, such as Incineration Fly Ash (IFA) and dredged materials, are available in large volumes and usually take a heavy toll on existing disposal facilities, which are very limited in volume and expensive to build in Singapore. Dredged materials are usually characterized by high moisture contents, high compressibility and low shear strengths. IFA is composed of fine particles with low shear strength. Both waste materials contain toxic contaminants and traces of metallic elements. The electrodes used in this treatment were (a) a new generation of Electrically conductive Vertical Drains (EVDs), which was made up from polymers of improved conductivity, and (b) a conductive geosynthetic fibre fabric. This paper presents the results obtained from series of laboratory model studies on the treatment of IFA and dredged materials. Results showed that Electro-kinetic Remediation (EKR) of IFA and dredged materials led to an improvement in geotechnical properties of the treated waste materials and also reduced the concentration of metallic elements in the soils between the electrodes. The importance of effective drainage at the cathode in EKR treatment is also highlighted.

1 INTRODUCTION

This paper reports on the treatment of Incineration Fly Ash (IFA) and dredged materials by Electro-kinetic Remediation (EKR) for reutilization. EKR involves the movement of different types of ions through the soil sample by four different major mechanisms, namely electrolysis, electro-migration, electrophoresis and Electro-osmosis (EO). Electrically conductive Vertical Drains (EVDs) mostly utilize EO in soil improvement treatments. The treated soil possesses a net negative charge upon the application of a voltage gradient resulting in attraction and clustering of cations to the soil surface. Cations are attracted to the cathode and anions to the anode. The water molecules that are clump around the ions in the pore space are brought along with the migrating ions. The net water flow is towards the cathode. Series of laboratory model tests were conducted in specially designed EKR cell and chamber. Conductive geosynthetic materials were used as the electrodes in this treatment.

Waste materials in Singapore, such as IFA and dredged materials are available in large volumes and usually take a heavy toll on existing disposal facilities, which are very limited in volume and expensive to build in Singapore. Dredged materials are usually characterized by high moisture contents, high compressibility and low shear strengths. Incineration ash, which is obtained through the incineration of municipal solid wastes, especially IFA, is composed of fine hollow structured powdery particles with low shear strength and high permeability. Both waste materials contain toxic contaminants and traces of metallic elements. Re-utilization of these waste materials will help to relieve the burden imposed on existing dumping facilities and may even serve as an alternative source of imported landfill materials.

Karunaratne et al. (2002) reported the use of EVDs as electrodes in a field trial for consolidation of soft clays conducted in 2001.

Hamir et al. (2001) reported the use of electrically conductive geosynthetics as electrodes/drains in electro-osmotic consolidation. The results from laboratory tests proved that these electrodes were as efficient as copper electrodes with little deterioration in the filtration and drainage of the pore water.

Shang (1998) reported the use of an analytical model for electro-osmotic consolidation combined with preloading via the use of vertical drains.

Lo et al. (1992) reported the use of alternating current at high voltages to induce net movement of water in the clay mass towards the direction of stronger electric field intensity. The results of the laboratory tests showed an improvement in shear strength and a 25% reduction of moisture content.

The new generation of EVDs used in this study was fabricated from polymers of improved conductivity of at least 100 times as compared to the previous EVD used in Karunaratne et al. (2002). Special treatment was done to further enhance the conductivity of these EVDs, resulting in an improved efficiency of the passage of circuit current through the soil. Besides this EVD, a conductive geosynthetic fibre fabric fabricated from polymers of higher conductivity than the EVD, was used.

The scope of this paper focuses on the improvement of geotechnical properties and the reduction of metallic concentration due to EKR treatment.

2 EXPERIMENTAL SET-UP AND PROCEDURES

2.1 *Electro-kinetic Remediation (EKR) cell and instrumentation*

A special Electro-kinetic Remediation (EKR) cell, which has dimensions (L × W × H) of about 1000 × 540 × 1000 mm (Fig. 1), was fabricated for the conduct of the laboratory model tests. Two sets of tests were conducted, designated as Series 1 and 2 for Incineration Fly Ash (IFA) and dredged materials respectively. The instrumentations for both series were essentially the same. Voltage drop measuring devices were designed to monitor the voltages at various pre-determined locations. These readings were continuously recorded and monitored. The analysis of this data is beyond the scope of this paper.

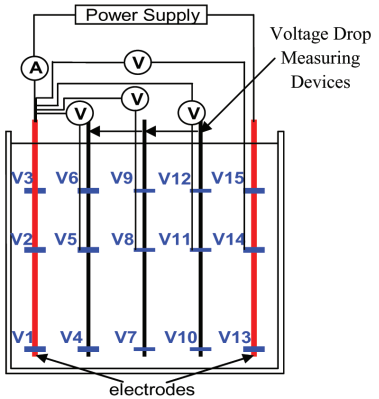

Figure 1. Schematic view of EKR cell.

2.2 *EKR chamber and instrumentation*

A cylindrical EKR chamber (Fig. 2) was specially designed to allow for easy drainage of water through the central cathode, which had drainage holes. The diameter and height of this chamber was 200 and 300 mm respectively. This EKR chamber was used to conduct test series 3, which involved the treatment of the same batch of dredged materials as test series 2.


Figure 2. Pictorial view of EKR chamber.

2.3 *Test procedures*

Soil samples were prepared and filled into the EKR cell or chamber at an initial moisture content of about 80% and 100% for dredged materials and IFA respectively. After the EKR cell was filled with the soils to be treated, the EVDs were inserted near the two sides of the EKR cell. In the case of the EKR chamber, the geosynthetic fibre fabric, which acts as the anode, was lined on the wall of the chamber before it was filled with soil to be treated.

Throughout the duration of the treatments, the current passing the circuit was maintained at desired values while the applied voltage was allowed to adjust accordingly. The circuit current was stepped-up from 2 A to a maximum of 10 A. Each test series was concluded when the soil resistance, computed from measured applied voltage and circuit current, were deemed to be too high (i.e. ~1.0 kΩ/m^3), which will render EKR no longer effective.

3 RESULTS AND DISCUSSIONS OF TEST SERIES 1 AND 2

3.1 *Shear strength*

The undrained shear strength of the soil samples were measured using the standard laboratory vane shear apparatus. For test series 1, the initial moisture content of 100% was used as this was the amount where all the water could be absorbed by Incineration Fly Ash (IFA) with no apparent free water on the surface. Figure 3 shows a summary of the undrained shear strength before and after the Electro-kinetic Remediation (EKR) treatment for all 3 test series. For test series 1, the results showed that it had an undrained shear strength of about 2–3 kPa before

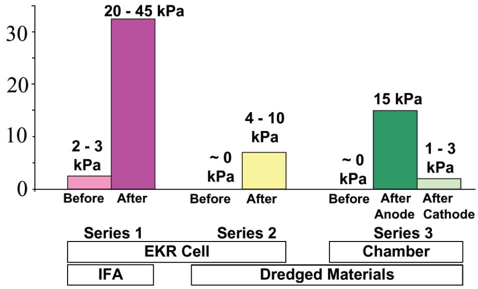

Figure 3. Undrained shear strength results.

treatment and improved to about 20–45 kPa after treatment. It was observed that there was no distinct difference in strength between the region around the anode and that around the cathode. It is noted that in the case of Electro-osmosis (EO) treatment on soft clayey soils, the soil near the anode will achieve higher shear strength than the soil near the cathode as the water flows from the anode to the cathode during EO. In this case, the movement of metallic ions in IFA, due to other EKR processes, led to a more uniform EKR treatment over the whole volume from cathode to anode. In particular, most metallic ions will move towards and deposit at the cathode. Thus, the shear strength increase of soil in the region around the cathode may be attributed to the possible metallic ions deposition in this EKR treatment.

In test series 2, the dredged materials with negligible initial shear strength was used. The initial moisture content was about 80%, which is two times the liquid limit. The undrained shear strength of the dredged materials after EKR treatment was found to be in the range of 4–10 kPa. Similar to series 1, the EKR treatment was uniform over the volume from cathode to anode. The shear strength increase was less than that in series 1 as water accumulated around the cathode was not drained off effectively due to the lower permeability of dredged materials as compared to IFA.

3.2 *Moisture content*

The initial moisture contents for test series 1 and 2 were 100% and 80% respectively. Soil samples were extracted from the EKR cells after treatment to determine the moisture content profile at various locations.

The moisture content of the IFA after treatment in series 1 was in the range of 62% to 80%. This showed a normalized reduction of 20–40% of the initial moisture content. The moisture content of the soil samples extracted around the cathode were only slightly higher than those samples extracted around the anode. The reduction of moisture content of the IFA was also observed to have increased with depth. For samples extracted from the mid-depth, the normalized moisture content is shown in Figure 4. This figure also showed that the difference in moisture content between the cathode and anode was less significant as compared to the case where EKR was used to treat clayey soils (Wan and Mitchell 1976). This could be due to the presence of metallic ions in IFA. The movement of these ions due to electrical charge helps in the flow of water molecules, resulting in a more uniform distribution of moisture content.

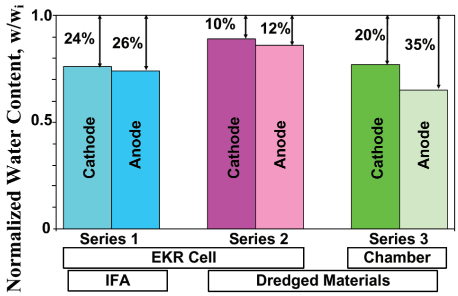

Figure 4. Normalized moisture contents of samples at mid-depths after EKR treatment for test series 1 to 3.

The moisture content of the dredged materials after treatment in series 2 was about 70%, which yielded a normalized reduction of 10–12% of the initial moisture content. This is consistent with the marginal gain in shear strength in this case. Figure 4 also showed that there was only very marginal difference in moisture content reduction between the anode and cathode in test series 2.

Comparing test series 1 and 2, it was shown that the moisture content reduction was greater for test series 1 than test series 2. This result was found to be consistent with the observed gain in shear strength reported in Section 3.1.

3.3 *Metallic ions concentration*

The presence of metallic ions may have increased the efficiency of the EKR treatment and reduced the soil electrical resistance, but its concentration needs to be reduced so that the waste materials can be re-utilized as landfill materials. Some of the metallic ions found in the untreated waste materials are hazardous to human and the environment, eg. Lead and Zinc.

Soil samples were extracted from the EKR cell at various locations and sent for chemical analysis to determine the concentration of metallic ions present in the treated soils. Table 1 summarizes some of the more significant changes in concentration of metallic ions before and after EKR treatment.

Significant changes in concentration of Zinc and Lead were observed for IFA, thereby reducing the toxicity of the treated IFA. In the case of dredged materials, the most significant changes were noted for the concentrations of Calcium and Iron.

Table 1. Summary of some metallic elements concentration before and after EKR treatment (unit = ppm).

Soil Sample	Test Series	Metals	Zinc	Lead	Calcium	Iron
Incineration	1	Before	60	15.8	1821	210
		After	40	7.5	1757	254
Fly Ash	2	Before	9.8	1.4	231	737
		After	9.7	1.6	155	512
Dredged Materials	3	Before	11.4	2.1	271	347
		After	8.5	1.5	206	269
Sale Levels			10	5	–	–

EKR treatment results in the mobilization of the metallic ions. They in turn move towards the respective electrodes based on the charge of the metallic ions. This may therefore result in a possible reduction of metallic ions concentrations in most regions of the soil except around the electrodes.

4 RESULTS AND DISCUSSIONS OF TEST SERIES 3

The results for the normalized moisture content reduction and the gain in shear strength of the treated dredged materials was 20–35% (Fig. 4) and about 3 –15 kPa (Fig. 3) respectively. A quick comparison of results showed that test series 3 had a greater moisture content reduction than test series 2, which used the same dredged materials. Test series 3 was designed specifically to evaluate the effect of drainage condition near the cathode. With the provision of drainage holes around the central cathode, leading to a sink out of the chamber, those water moving towards the cathode will be effectively drained off. Thus this will result in a very effective dewatering scheme.

It should be noted that the highly conductive Geosynthetic Fibre Fabric was chosen as the electrode in test series 3 mainly due to its soft and flexible fabric-like nature, rather than its improved conductivity over the EVDs used in test series 2. Similar results of test series 2 were obtained when more conductive electrodes (eg. Aluminum or steel, with similar conductive as Geosynthetic Fibre Fabric) were used.

It was observed that the amount of water collected increased significantly as a result of better drainage in test series 3. This was largely attributed to the improved drainage. In addition, comparing the results of IFA (test series 1) and dredged materials (test series 2 and 3), it can be implied that the presence of metallic elements in the soils play a significant role in increasing the efficiency of the EKR treatment.

5 CONCLUSIONS

This paper reports on the treatment of Incineration Fly Ash (IFA) and dredged materials for subsequent re-utilization. Dredged materials are characterized by high moisture contents, high compressibility and low shear strengths while IFA is composed of fine particles usually with low shear strengths. Both waste materials contain toxic contaminants and traces of metallic elements and will need to be detoxified before they can be re-utilized or recycled as backfill materials in civil engineering projects.

These series of tests used a new generation of Electrically conductive Vertical Drains (EVDs) which is 100 times more conductive than the EVDs used previously, as well as a highly conductive Geosynthetic Fibre Fabric as electrodes.

The results from test series 1 and 2 showed that there were improvements in the moisture contents and shear strengths of the treated soils after EKR treatment. There were also visible changes in the metallic composition of the treated soils and hence resulting in the possible detoxification of the soils. The presence of the metallic elements in the waste materials led to an improved efficiency of EKR treatment, due to the mobilization of metallic ions and reduction in soil electrical resistance.

The results from test series 3 showed a greater improvement in the final moisture content and shear strength than that of test series 2. This highlights the importance of better drainage at the cathode such that water will be drained off efficiently.

From a practical point of view, the toxicity of the waste materials have been reduced to a safe level and along with the strength improvement, they can therefore be recycled and re-utilized as landfill and backfill materials. They may serve as an alternative source of the currently imported landfill materials.

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