Electro-kinetic techniques and geotextiles for high water content sludge dehydration tests

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ABSTRACT
This study evaluates the use of Electro-Kinetic (EK) techniques and geotextiles to dehydrate high water content sludge obtained from a local watershed reservoir. A model test provided the de-hydration process for the high water content sludge using a geo-bag and electro-kinetic technique. Different electrode metal materials with various setups and different voltages were used in this study. The liquid limits and plastic index of the sludge mud are 33% and 10%, respectively. Geo-bags were made from a polyester multi-filament geotextile. The diameter and height of the geo-bags are 24 cm and 36 cm, respectively. The preliminary study indicated that PET geotextile geo-bag is a good filtration material for high water content sludge for dehydration applications. Steel and aluminum are very corrosive materials for this process. Low dehydration rates were obtained using a copper rod as the anode electrode. Stainless steel is a corrosion resistance material with a good dehydration performance. Using a single stainless steel rod with 60V for EK dehydration process would reduce the water content from 100% to around 50% within 4-8 hours. The decrease in electrode distance with increasing number of electrodes would increase the dehydration process efficiency. The results from this study can be a valuable reference for developing geotextiles with electro-kinetic techniques for full scale sludge dehydration applications.

Keywords: Sludge dehydration, Electro-kinetic technique, Geotextiles, Geosynthetics.

1. INTRODUCTION
The annual Taiwan precipitation is more than 2500 mm. However, more than 80% of the rainfall is concentrated in the summer rainy season. Besides the un-even rainfall distribution, the catch basin of the typical river in Taiwan is relatively small. The river length is short and the river slope is much steeper than that for typical continental rivers around the world. Because of these reasons, the time required for water to flow from the mountain top areas to the ocean is less than two or three days in Taiwan. Therefore, building dam reservoir to maintain a steady water supply is an important infrastructure in Taiwan. However, slope soil erosion due to heavy rainfall will transfer the eroded soil particles into the dam reservoir. Large amounts of sludge forming in the bottom of dam reservoirs present significant challenges to the lifespan of dam reservoirs. Thus, dredging dam sludge is a big task for the water resource authority in Taiwan. This high water content dredge sludge normally requires a very long time to settle in order to be able to transfer it from the job site for further usage. Therefore, accelerating high water content sludge dehydration is an important and interesting research topic for engineers. The objective of this study is to evaluate the feasibility of combining the Electro-Kinetic principle and geotextiles to speed up the de-hydration process for high water content sludge obtained from a dam reservoir in Taiwan.

2. RELATED RESEARCHES
The electro-osmosis phenomenon has been known for almost 200 years. Its applications in ground engineering has been limited due to electrode problems associated with electrochemical corrosion and the inability to effectively conduct the flow of water and gases. However, the invention of electro-kinetic Geosynthetics (EKG) has overcome these problems and allowing the functionality of electro-kinetics to be combined with Geosynthetic functions for drainage, reinforcement filtration, separation and containment (Lamont-Black et al., 2006).

EKG have been identified as a platform technology...
that combines a wide variety of materials, functions and processes to perform such diverse functions as dewatering, strengthening and conditioning materials such as soils, sludge, slurries, tailings and composts. Applications have been identified in a range of industrial sectors including water resource management, mining, civil and environmental engineering, food and sports.

The state of research for Electro-kinetic Geosynthetic (EKG) technology is discussed in detail by Jones et al. (2008). Fourteen separate functions were reported between electro-kinetics and Geosynthetics. A wide range of new applications have been established for EKG materials that cannot be addressed using conventional geosynthetic materials. Electro-kinetic components, their key parameters, effects and implications are also discussed by Jones et al. (2008).

Research into EKG applications and material development is being conducted in a number of countries, such as Australia, Canada, China, Germany, Singapore, Thailand, UK, USA, etc. In general, EKG is currently being developed and applied to six broad application areas, water, food, mining, civil engineering, sport (horticulture), and geo-environmental engineering, etc.

Zhuang et al. (2006) conducted a series of model tests to study the EK reinforcement effect on increasing the stability of saturated soft clay slopes. Electro-kinetic soil strengthening has been undertaken by a number of practitioners including: Casagrade (1949, 1952, 1983), Fetzer (1967), Bjerrum et al. (1967), Chappell and Burton (1975), Lo et al. (1991a, and b, 2000). The EK technique was also used for the dewatering and consolidation of mine tailings by: Sprute and Kelsh (1975), Lockhart (1983), Shang (1997). Cementation agents and bio remediation agents have been introduced into the soil through a technique used by Mohomadelhassan and Shang (2003) and Shang et al. (2004). Chew et al. (2004) reported on an electro osmotic consolidation field trial using Singapore marine clay using EK drains. Using EK methods to dewater mining waste is a common practice in the mining industry. The EK belt press is a continuous method for dewatering, electro-kinetic prefabricated vertical drains (ePVDs) are used in-situ and EK bags and tubes suitable for batch processing (Jones et al, 2008). The soil nailing function can be enhanced using electro osmotic treatment (Hamir et al 2001, Milligan 1994).

Many tailing dams are formed using thickened tailings which can be susceptible to liquefaction when subjected to a seismic event. By combining soil nailing and EK technology, the susceptible material can be successfully stabilized (Milligan 1994). EKG applied to sports turf can yield significant improvements in the physical performance and chemical conditions of sport surfaces with the potential to improve reliability, performance and sustainability (Lamont-Black 2003, Lamont-Black et al 2006).

By combining the conventional geosynthetic products with the electro-kinetic principle to accelerate high water content sludge dehydration is evaluated in this study.

3. RESEARCH PROGRAM, MATERIALS, AND EQUIPMENT

The objective of this study is to evaluate the feasibility of using the Electro-Kinetic principle in combination with geotextiles to accelerate the dehydration of high water content sludge obtained from a local watershed reservoir. A schematic view of the proposed model apparatus is shown in Figure 1. The proposed apparatus consists of a perforated stainless steel cylindrical buckle, a geo-bag can be placed within the perforated buckle, and metal rod(s) set at the center of the geo-bag. A plastic buckle with a drainage pipe was used to hold the stainless buckle for water flow measurement. The anode was connected to the center pole and the cathode was connected to the perforated stainless steel buckle. The water filtrated from the geo-bag was collected at bottom of the apparatus for weight measurement. An electronic balance with automatic data collection system was used in this study.

![Schematic view of the electro-kinetic (EK) filtration test system.](image)

3.1 Test materials

The test sludge was obtained from a watershed reservoir, Chen-Chin Lake. Chen-Chin reservoir is primary water basin for the drinking water of Kaohsiung City. The typical physical properties of these materials are summarized in Table 1. In general, the sludge is classified as low plasticity clayey or silty materials. The
liquid limits and the plastic index are 33% and 10%, respectively. These data indicate that the sludge contains a very low percentage of clay particles.

Table 1 Typical properties of the test soil

| Item               | Results          |
|--------------------|------------------|
| Classification     | CL (Lean clay)   |
| Liquid limit (LL)  | 32.92%           |
| Plastic limit (PL) | 22.71%           |
| Plastic index (PI) | 10.21%           |

A polyester yarn woven geotextile was used to make the geo-bags for this study. The geotextile engineering properties are summarized in Table 2. The permittivity and apparent opening size are 0.138 1/s and 0.296 mm, respectively.

Table 2 Typical properties of the test PET multiple filament woven geotextile

| Item                     | Test Method | Units | Test results |
|--------------------------|-------------|-------|--------------|
| Mass per unit area       | ASTM D3776  | g/m2  | 323.33       |
| Thickness                | ASTM D5199  | mm    | 1.20         |
| Tensile Strength         | ASTM D4632  | kN    | 4.05         |
| Apparent opening size    | ASTM D4751  | mm    | 0.296        |
| Cross-Plan Permeability  | ASTM D4491  | Sec-1 | 0.138        |

3.2 Test program

The initial water content of all test soil sludge was prepared with a water content of 100%. The initial soil weight and water weight were equal to each other. The filtrated water was collected by placing a basin at the bottom of the filtration bucket. The water weight was measured continuously and recorded using an electronic balance and data logger as shown in Figure 1. The sludge water content can be calculated by subtracting the water weight filtrated during the test. The test program included a natural filtration reference test using the polyester woven geo-bag. The electro-kinetic filtration test variables included electric voltage, number of anode poles, and metal material for anode pole. The anode pole materials included aluminum, iron, and copper. Corrosion was present during the test for these three materials. Stainless steel was further investigated in the final stage of this study. 10V, 20V, 30V, 40V, 50V, and 60V were used to evaluate the voltage effect on EK filtration. Single, double and four anode poles were used to evaluate the pole distance effect on the EK filtration test. The complete test program is listed in Table 3. More than 16 filtration tests were conducted in this study.

4. RESULTS AND DISCUSSIONS

The test polyester multifilament woven geotextile consists of very good permittivity property. It is a very good filtration product. However, the filtration behavior is also related to the test soil particle distribution. Based upon the soil classification test results, the test lake deposit is all finer than #200 sieve. The liquid limit is about 33%, and the plastic index (PI) is about 10%. The unified classification indicated that the soil is a low plasticity clayey or silty soil. The water content for the natural filtration reference test reduced from 100% to 54% and 44% for 3 days and 7 days, respectively. The de-hydration of this fine clayey material required a 7-day natural filtration process before the sludge could be transported for further processing. The variation in water content versus duration for the EK/GT filtration tests for various single metal rods with 10V is shown in Figure 2. Using rods made of different metals showed no significant influence on the de-hydration process.

The final water contents for the EK/GT filtration test using various single metal rods with different voltages for 3-days duration are shown in Table 4. The results indicated that using 30V showed some effect in accelerating the de-hydration process for the conditions using aluminum or copper rods for the anode pole. Using aluminum rods with 30V showed better dehydration capability than the other two rods.
The number of poles and pole distance effects were also evaluated for EK/GT filtration tests. Copper metal rods and 30V were used for single, double, or four rods EK/GT filtration tests. The test duration was 72-hours. The results are summarized in Table 5. The EK process would speed up the dehydration process; however, increasing the number of anode poles has some effect on increasing the dehydration process in the first 4 hours. The increasing voltage and number of anode poles effects for the EK/GT filtration test are summarized in Table 6. Increasing the EK process voltage showed better influence than increasing the number of anode poles for the dehydration process.

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Table 4 Final water contents of various EK/GT filtration tests with 3-day duration. Unit: %

| Rod Type | 10V | 20V | 30V | 50V |
|----------|-----|-----|-----|-----|
| Copper   | 50.7| 47.5| 47.3|     |
| Iron     | 47.6| 47.9| 46.2|     |
| Aluminum | 52.3| 51.3| 41.3|     |

Note: The final water content for 3-day duration natural filtration reference test is 53.4%.

Table 5 Summary of the water contents for various EK/GT filtration tests using 30V and different number of copper anodes setup. Unit: %

| Test Group | Duration (hour) | 0.5H | 1H | 2H | 4H | 8H | 12H | 24H | 72H |
|------------|----------------|------|----|----|----|----|-----|-----|-----|
| Reference  | 88.0           | 83.8 | 78.9| 73.3| 66.2| 63.4| 60.0| 53.4|
| Single-pole| 87.8           | 82.2 | 74.6| 65.0| 56.6| 55.4| 53.5| 47.3|
| Double-pole| 85.5           | 77.4 | 66.7| 57.2| 54.0| 53.4| 51.9| 47.6|
| Four-pole  | 83.4           | 74.1 | 61.8| 53.1| 51.7| 51.0| 49.5| 46.2|

Table 6 Summary of water contents for various EK/GT Filtration tests with different voltages and pole number (copper metal pole). Unit: %

| Test Group | Duration (hour) | 0.5H | 1H | 2H | 4H | 8H | 12H | 24H | 48H | 72H |
|------------|----------------|------|----|----|----|----|-----|-----|-----|-----|
| Reference  | 88.0           | 83.8 | 78.9| 73.3| 66.2| 63.4| 60.0| 53.4| 47.6| 40.6|
| 30V single | 87.8           | 82.2 | 74.6| 65.0| 56.6| 55.4| 53.5| 47.3| 40.6| 34.5|
| 30V double | 85.5           | 77.4 | 66.7| 57.2| 54.0| 53.4| 51.9| 47.6| 40.6| 34.5|
| 30V four   | 83.4           | 74.1 | 61.8| 53.1| 51.7| 51.0| 49.5| 46.2| 40.6| 34.5|
| 40V single | 86.5           | 80.2 | 71.9| 61.7| 53.2| 52.2| 50.6| 40.6| 34.5| 28.4|
| 50V single | 86.5           | 79.2 | 68.6| 56.1| 52.2| 51.4| 49.2| 40.6| 34.5| 28.4|
| 60V single | 86.0           | 77.7 | 64.9| 51.6| 48.9| 47.9| 45.5| 40.6| 34.5| 28.4|

5. SUMMARY AND CONCLUSION

A model test combining the Electro-Kinetic (EK) technique with geo-bags to dehydrate high water content sludge was evaluated in this study. The test soil was obtained from a local watershed reservoir and classified as a low plasticity clayey or silty soil. The liquid limits and plastic index of the sludge mud were 33% and 10%, respectively. Geo-bags were made from a polyester multifilament geotextile. Different electrode metal materials with various arrangements and different voltages were used in this study. The preliminary study indicated that PET geotextile geo-bag is a good filtration material for high water content sludge dehydration applications. The EK process would speed up the dehydration process; however, increasing the number of anode poles has some effect on increasing the dehydration process in the first 4 hours. Steel and aluminum are very corrosive materials for this process. Stainless steel is a corrosion resistant material with good dehydration performance. Increasing the EK process voltage showed better influence than increasing the number of anode poles for the dehydration process. Decreasing the electrode distance with increasing the number of electrodes would increase the efficiency for the dehydration process. The results from this study can be a valuable reference in developing geotextiles with electro-kinetic techniques for full scale sludge dehydration applications.
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