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Large-scale testing of electro-osmosis with enhanced wick-drain techniques for dewatering iron mine tailing

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Abstract. In geotechnical engineering, two conventional methods, electro-osmosis, and wick drains (also known as prefabricated vertical drains or PVD), are commonly employed to mechanically enhance fine-grained saturated soils. This research aims to combine these two methods to develop a novel approach. Various configurations were examined, and comparisons were made between the new product and each method individually to identify the optimal configuration, pattern, and degree of improvement. Samples were collected from the thickener at the Golgohar iron ore mine and arranged into seven large-scale testing pools. Square and triangular patterns, along with constant and alternating poles, were investigated in this study. The results demonstrated that the combination of these technologies improved the mechanical properties, with the most significant enhancement in undrained shear strength observed in pools employing an enhanced Wick drain featuring constant poles and a triangular pattern.

1 Introduction

The installation of prefabricated vertical drains, commonly known as wick drains, is a widely employed technique in fine-grained and saturated soils. Wick drains serve to reduce drainage distances by facilitating water flow through the shortest path within the saturated layer. Typically, wick drains are used in conjunction with surcharge methods, such as embankments, pools, heavy construction machinery, nailing, and electro-osmosis. Electro-osmosis is another prevalent method used for remediation in fine-grained and saturated soils. By combining these two methods, improved and expedited outcomes can be achieved.

Since 2000, electrokinetic geosynthetics (EKG) have emerged as a composite of these two methods. Extensive research and numerous publications have been dedicated to exploring the potential of EKGs. These conductive geosynthetics offer the combined advantages of wick drains and electro-osmosis.

In this study, a similar concept is utilized, but with the development of a new product. This product combines electrodes with conventional wick drains, which can even be created using scrap metals, making it a more sustainable option. Notably, this product has been patented in Iran.

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2 Previous Research

Lemont-Black et al. (2005) investigated the use of EKG for in-situ dewatering of sewage sludge. They observed that the removal of topwater led to improved electro-osmotic dewatering, resulting in increased solid content and shear strength.

Fourie (2006) utilized EKG for the dewatering of wet cohesive fill to achieve a specific shear strength. He identified challenges associated with the electro-osmosis technique, such as electrode corrosion, loss of soil-electrode contact, excessive energy consumption, and logistical water collection issues. However, he believed that EKG addressed the corrosion problem, making it a viable solution for various applications.

Fourie et al. (2007) employed EKG for in-situ dewatering of sand mine tailings and achieved a reduction in water content from 158% to 75% with low energy consumption (0.9 kWh/dry tonne). They attributed this success to the use of a low voltage gradient (0.11 V/cm) and suggested further investigations on different tailings.

Lemont-Black (2007) emphasized that diamond mine tailings were suitable candidates for electro-osmotic dewatering, as reduced moisture content facilitated easier conveyor transportation. Additionally, Hall et al. (2008) demonstrated that EK filtration bags could effectively dewater materials, making them easier to handle manually or with machinery, which is particularly advantageous in mine tailings.

Shenbaga et al. (2011) conducted experiments on consolidation using EKG and found that drained water primarily collected at the cathode. They determined that a voltage gradient of 120 V/m yielded optimal electro-osmotic consolidation results. Similarly, Karunaratne (2011) compared wick drains and EKG for soft clay consolidation and concluded that EKG significantly accelerated the consolidation rate.

Colin et al. (2011) discussed various factors influencing EKG applications, such as legal requirements, climate change, carbon footprint reduction, water reclamation, and waste reduction and reuse. Glendinning et al. (2015) highlighted the significance of EKG in dewatering sludges and tailings, emphasizing its potential for active geosynthetic applications.

Zou et al. (2017) utilized an electrically conductive wick drain combined with an automated power supply to dewater hydraulically-filled sludge ground, resulting in an average moisture content decrease from 62% to 39%. Visigalli et al. (2017) demonstrated that electro-osmotic dewatering reduced moisture content by up to 42.9% in different types of sludge.

Tang et al. (2017) investigated electro-osmosis on marine soil and found that a higher voltage of 12V resulted in an average water content decrease of 9.3% more than at 6V. They also observed greater water content reduction on the anode side, with the middle water content closer to the anode side.

Fu et al. (2017) studied drainage effects during intermittent and reverse electrifying periods in electro-osmosis. They found that the drainage effect during a 1-hour power-off mode was equivalent to that during a 0.2-0.25-hour electrifying reverse period.

Bourges-Gastaud et al. (2017) evaluated the effectiveness of electrokinetic geocomposite on sand tailings and achieved a solids content increase from 45% to approximately 70%. This transformation from fluid fine tailings (FFT) to mature fine tailings (MFT) reduced the risk of leaks, failure, and migration of contaminants.

3 Preparation of Samples and Novel Drainage Media

In this study, a newly patented drainage media was utilized, combining electrodes and Wick drains to harness the advantages of both methods simultaneously. To achieve this, CeTeau's wick drain was selected and modified to accommodate the electrodes. Figure 1 illustrates a comparison between the patented drainage media (wick drain and electrode) and the original CeTeau's wick drain.

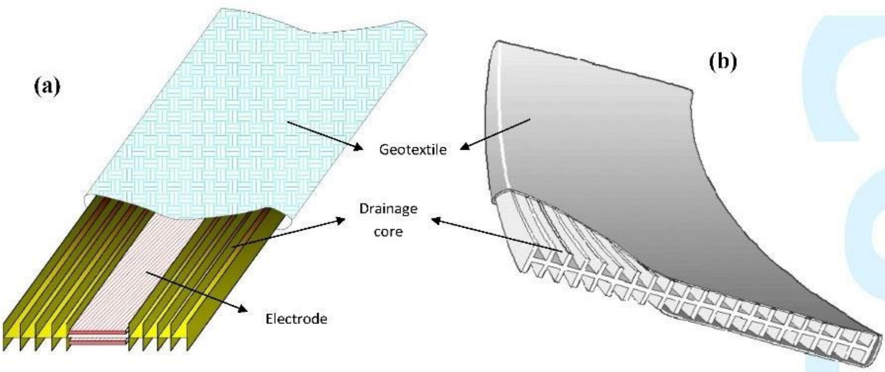

Fig. 1. (a) Patented drainage media (wick drain and electrode) (b) original CeTeau’s wick drain.

In this study, six pools with dimensions of 3.88m x 2.96m and a depth of 2.3m were utilized. These pools were filled with iron tailings obtained from the thickener in the form of slurry, up to a depth of 1.8m. The dry tailings underwent soil classification testing, resulting in a classification of ML (Silt). The particle distribution is presented in Figure 2.

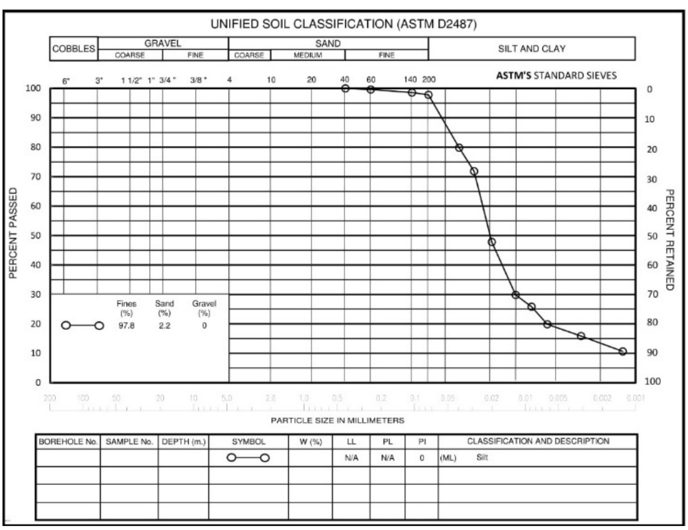

Fig. 2: Unified Soil Classification Curve of the Tailing Utilized in this Study

After the pools were filled, the new drainage product (electrode and Wick drain) and electrodes were manually installed in the pools following the pattern depicted in Figure 3. Subsequently, a one-day setting time was allotted, and any excess water accumulated on the surface was removed using a siphon. The arrangement of the pools and electrodes was as follows:

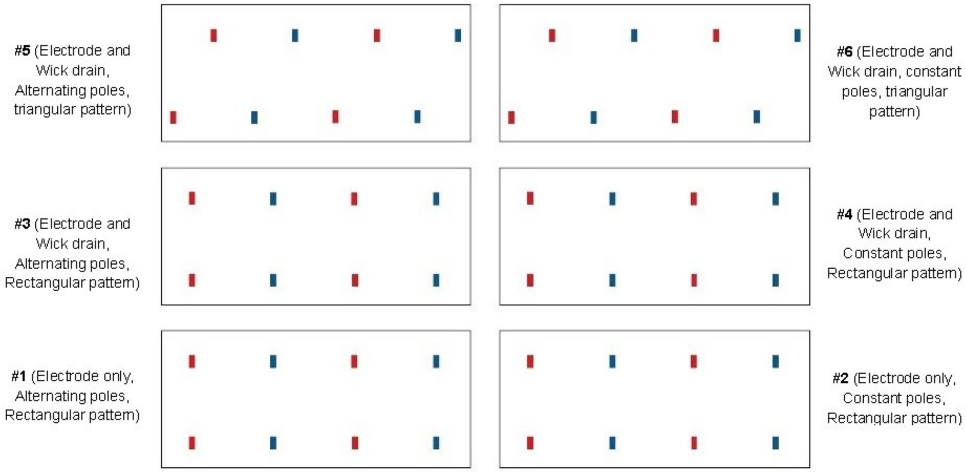

Fig. 3. The pattern of treatment in the pools.

In the provided image, it is evident that pools #1, 2, 3, and 4 feature a square pattern, while pools #5 and 6 exhibit a triangular pattern. Figure 2 illustrates the blue electrodes as cathodes and the red electrodes as anodes. Notably, the poles in pools #2, 4, and 6 were alternated on a daily basis. Furthermore, pools #1 and 2 were equipped solely with electrodes, whereas the other pools utilized a combination of Wick drains and electrodes. This installation enables a comprehensive comparison of the pattern's impact, alternating poles versus constant poles, as well as the performance of the new product with electrodes alone.

A DC rectifier with a voltage of 48V served as the power supply, with an electrode spacing of 1m, resulting in a voltage gradient of 48V/m. Figure 4 provides a depiction of how the new drainage product was installed in pool #4, with red cables connecting the anodes and blue cables connecting the cathodes to the electrical power source. Fig. 4 shows the pattern of electrodes in the pools, and Table 1 shows the configuration of each pool.

Fig. 4: Installation of the New Drainage Product in Pool #4

Table 1. Configuration of Pools

Pool#	Type of Treatment	Pattern	Pole Change?
1	Electro-osmosis	Rectangular	Yes
2	Electro-osmosis	Rectangular	No
3	Enhanced	Rectangular	Yes
4	Enhanced	Rectangular	No
5	Enhanced Body	Triangular	Yes
6	Enhanced	Triangular	No
7	Enhanced	Rectangular	N/A

3.1 Test procedure

At the beginning of the test, the slurry had an initial solid content of approximately 50%. Coagulant was present in the tailing samples, which were obtained from the thickener. After a one-day setting time, the solid portion of the tailing settled, and the clear water on top was siphoned out. As the test progressed, the slurry transformed into a paste-like consistency. Each day, soil samples were collected from the surface near each electrode at an equal distance, ensuring comparability. It is important to note that after the initial days of the test, there was no free water on the surface to be siphoned as most of it had evaporated. The moisture content measurements over time are depicted in Figures 5 and 6. The samples were taken from a consistent radius around similar electrodes to ensure comparability, although some fluctuations are observable in the graphs. Similar fluctuations were also reported by Barooti et al. (2019), whereas Lemond-Black et al. (2005) observed a smoother trend in their study.

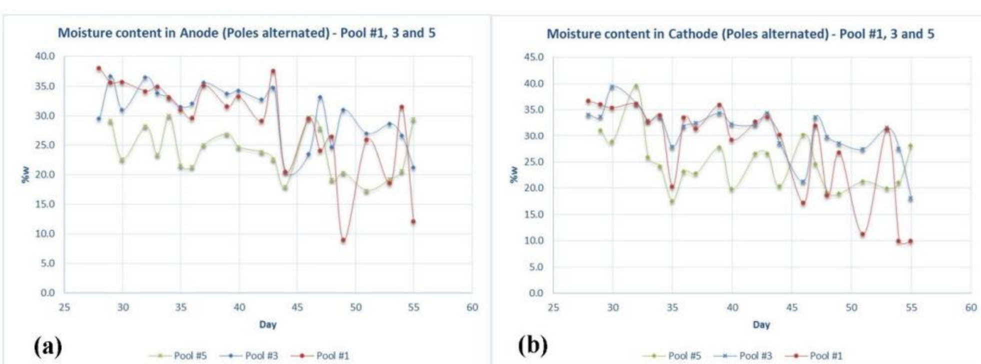

Fig. 5. (a) Moisture content in Anode-Pool #1, 3, and 5, (b) Moisture content in Cathode-Pool #1, 3, and 5.

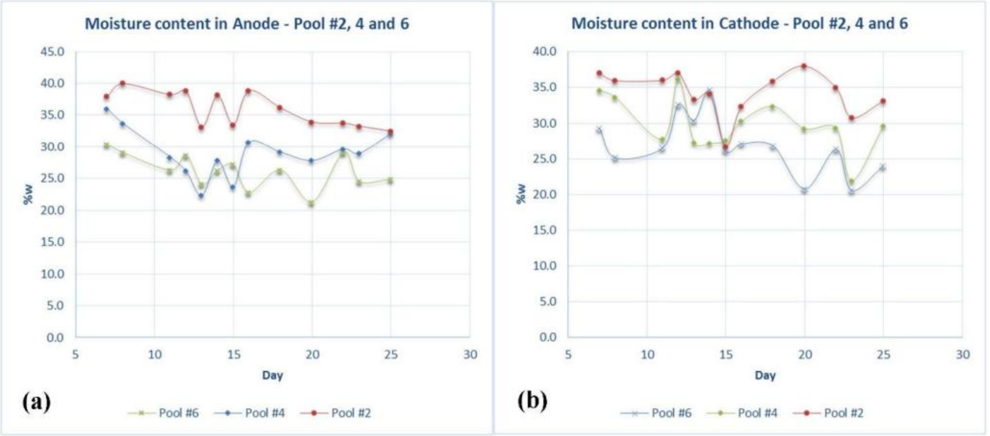

Fig. 6. (a) Moisture content in Anode-Pool #2, 4, and 6, (b) Moisture content in Cathode-Pool #2, 4, and 6.

In each pool, two test pits were excavated to measure the moisture content at various depths. Samples were collected at intervals of 20cm along the test pits. The excavation of the test pits was done at the center of the electrodes. The moisture content results at different depths are presented in Figures 7 and 8. The terms "red" and "blue" are used to differentiate between anode and cathode. However, in the pools where the poles alternated (i.e., pool 1, 3, and 5), there was no distinction between the poles.

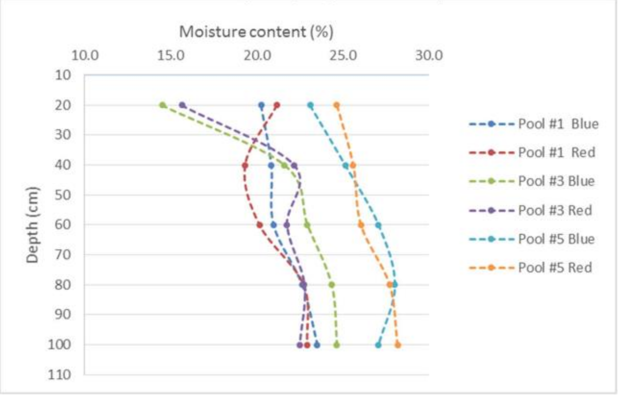

Fig. 7. Moisture content in depth-Pool #1, 3, and 5

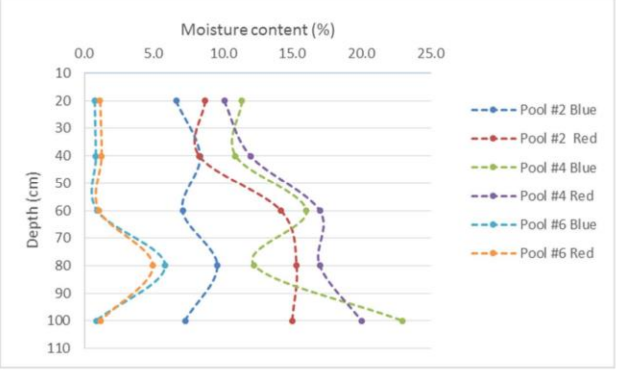

Fig. 8. Moisture content in depth-Pool #2, 4 and 6

3.2 Analysis of the results

In pools #1, 3, and 5, where the poles were alternated, there was a greater reduction in moisture content measured adjacent to the electrodes on the surface compared to pools with constant poles. However, the overall decrease was only around 5%, and the moisture content on the anode and cathode sides remained relatively unchanged.

Figures 7 and 8 illustrate that, in general, the moisture content increased with depth. It is important to note that the results in these figures show lower total moisture in pools #2, 4, and 6, which is contrary to the surface moisture content results. This discrepancy can be attributed to the fact that the samples taken from around the electrodes on the surface were consistently wet, indicating the effectiveness of the combination of electrodes and wick drains in bringing water to the surface. However, relying solely on the moisture content of surface samples taken near each electrode may not accurately represent the overall conditions.

Therefore, studying moisture content at different depths between two electrodes is crucial for drawing accurate conclusions. The reduction in moisture content was more pronounced in pool #6 across different depths (triangle pattern). In pools with alternating poles, the square pattern yielded better results (pools #3 and 5). Lemont-Black et al. (2005) conducted a comparison between a rectangular pattern and a hexagonal pattern, demonstrating that the hexagonal pattern led to a greater overall reduction in moisture content.

4 Conclusion

Wick drains and electrodes were combined to create a new product that utilized both techniques simultaneously for dewatering purposes. The soil under investigation consisted of iron mine tailings classified as silt (ML). Near the electrodes, the moisture content in the pools where the direct current alternated was reduced by approximately 5%. The maximum reductions were observed in pools #1, with a reduction of 70%, and pool #3, with a reduction of 40%, where constant poles were utilized.

Upon analysing the moisture content at different depths between the electrodes, it became apparent that the moisture content increased with depth. Interestingly, in pools #2, 4, and 6, which employed constant poles, a more significant reduction in moisture content was observed at various depths compared to the surface near the electrodes. This finding contradicts the observations made near the electrodes on the surface, where water accumulated in the case of constant poles. The results indicated that in pools utilizing constant poles, the total moisture content reduction was more pronounced in the middle of the electrodes.

The most favourable outcomes were achieved in pool #6, where the combined method of using both electrodes and wick drains was implemented alongside constant poles.
Captions should be typed in 9-point Times. They should be centred above the tables and flush left beneath the figures.

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