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Evaluation of the performance of wick drains (prefabricated vertical drains) enhanced by electro-osmosis method in the dewatering of Iron mine tailing

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ABSTRACT
Two classical methods, electro-osmosis and Wick drains (prefabricated vertical drain) are generally used in geotechnical engineering to improve fine-grained and saturated soils. In this research, these two methods were combined to create a new product, which was then compared to determine the best configuration and pattern t reduce the water content of the samples. Considering the large amount of mine tailing produced from mines in slurry form, which is a mixture of fine mineral particles and water, reducing the amount of water from mine tailings leads to water reuse. It increases the bearing capacity of the soil. Samples were taken from the thickener of the Golgohar Iron Ore Mine and were arranged in six reservoirs for field tests. Square and triangle patterns and constant and alternating poles were used and investigated in this study. The results showed that the total moisture content decreased, and the best result was for the combined method with constant electrical poles and a triangular pattern.

RESUMEN
Dois métodos clássicos, eletro-osmose e drenos Wick (dreno vertical pré-fabricado), são geralmente usados na engenharia geotécnica para melhorar solos granulados e finos. Nesta pesquisa, esses dois métodos foram combinados para criar um novo produto, que foi comparado para determinar a melhor configuração e padrão para reduzir o teor de água das amostras. Considerando a grande quantidade de rejeito de minas produzido a partir de minas na forma de chorume, que é uma mistura de partículas minerais finas e água, a redução da quantidade de água dos rejeitos de minas leva à reutilização da água e aumenta a capacidade de suporte do solo. As amostras foram retiradas do espessador da mina de ferro de Golgohar e dispostas em seis reservatórios para testes de campo. Padrões quadrados e triangulares e pólos constantes e alternados foram utilizados e investigados neste estudo. Os resultados mostraram que o teor total de umidade diminuiu e o melhor resultado foi para o método combinado com pólos elétricos constantes e padrão triangular.

1. INTRODUCTION

Installation of prefabricated vertical drains (Wick drains) is a common technique usually used in fine and saturated soils. Wick drains help shorten the drainage distance, allowing water to travel the shortest path of the saturated layer. Wick drains usually are used with surcharge. The surcharge can be an embankment, a pool, heavy construction machinery, nailing, and electro-osmosis. The electro-osmosis technique is another common method for remediation in fine and saturated soils. These two methods can be used together in order to achieve better and faster results.
Electrokinetic geosynthetics (EKG) are the combination of these two methods that are being used after 2000. During this time, lots of research has been done with this product and many papers published. EKGs are conductive geosynthetics that can be used to have both benefits and wick drains and electro-osmosis in the same time.
In this research, a similar idea was used, but with a new product. This product is a combination of electrodes and regular wick drains that can be made even by scrap metals. That is why it is a more sustainable product. This product was patented in Iran.

2. PREVIOUS RESEARCHES

Lemont-Black et al. (2005) used EKG for in-situ dewatering of sewage sludge. It was shown that removal of topwater is likely to lead to improved electro-osmotic dewatering, so solid content and shear strength would increase accordingly. EKG was used as a means for the dewatering of wet cohesive fill to reach a specific amount of shear strength. Fourie (2006) used EKG to dewater mine tailings. He believed that some difficulties were the main reasons to preclude widespread usage of the electro-osmosis technique, which includes the corrosion of electrodes, loss of contact between soil and electrodes, excessive energy consumption, and the logistical problem of water collection. Since EKG somehow solved the related problem of corrosion, he believed that this method can now be used to solve a variety of problems.
Fourie et al. (2007) used EKG for in-situ dewatering of sand mine tailing and reduced the water content from 158% to 75% at an energy consumption rate of 0.9kWh/dry tone. He concluded that this low value was due to utilizing a low voltage gradient of 0.11 V/cm and suggested that further investigation should be done on other tailings. Lemont-Black (2007) showed that diamond mine tailing was the right candidate for electro-osmosis dewatering, claiming that with decreased moisture content, the tailing can be transported by conveyor easily. Lemont-Black (2007) showed that

Diamond mine tailing was a good candidate for electro-osmosis dewatering, claiming that with decreased moisture content, the tailing can be transported by conveyor easily. Hall et al. (2008) showed EK filtration bags could be used to dewater material. Thus, later on, the drier material is easier to handle both by hand and with machinery that can be interesting in mine tailing. Shenbaga et al. (2011) performed some experiments on consolidation with EKG and reported that drained water was mostly gathered in the cathode and voltage gradient had a significant effect on electro-osmotic consolidation; it was determined that optimum results could be derived by a voltage gradient of 120 V/m. Karunaratne (2011) used wick drains and EKG for the consolidation of soft clay and concluded that EKG could increase the consolidation rate by many folds in comparison with Wick drains. Colin et al. (2011) concluded that EKG applications relate to several factors, including legal requirements, climate change, the need to reduce carbon footprints, reclamation of water, and reduction and reuse of wastes. Glendinning et al. (2015) concluded that active geosynthetics (EKG) could be used for dewatering that has significant implications in the treatment of sludges and tailings. Zou et al. (2017) used an electrically conductive wick drain combined with an automated power supply on hydraulically-filled sludge ground and showed that the average moisture content decreased from 62% to 39%. Visigalli et al. (2017) showed that electro-osmotic dewatering on different types of sludge could reduce the moisture content by up to 42.9%.

Tang et al. (2017) used electro-osmosis on marine soil and showed that the water content under 12V decreased, on average, about 9.3% more than 6V. Also, they showed that the water content decreased more in the anode side, and the middle water content is nearer to the anode side. Fu et al. (2017) studied the drainage effect during the elector-osmosis in intermitted and reverse electrifying periods. They showed that the drainage effect in the power-off mode for 1h was equivalent to that in the electrifying reverse period of 0.2-0.25h. Bourges-Gastaud et al. (2017) the effectiveness of electrokinetic geocomposite on soil sand tailing. They reached to a solids content of about 70% from an initial solids content of 45%. This can make a fluid fine tailing (FFT) to mature fine tailing (MFT) and reduce the risk of leaks, failure, and migration of contaminants.

3. PREPARATION OF SAMPLES AND NEW DRAINAGE MEDIA

In this research, a new drainage media was used that was patented in Iran. The idea was to combine electrodes and Wick drains to have both method's advantages as once. For this reason, CeTeau's wick drain was used and modified to accommodate the electrodes. The comparison between the original and the modified one can be seen in figure 1.

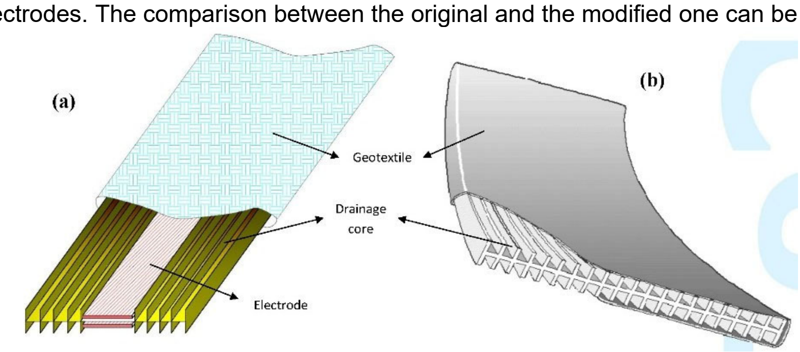

Figure 1. (a) Patented drainage media (wick drain and electrode) (b) original CeTeau's wick drain

The core is flexible polypropylene having high water flow capacity along the grooves, and the geotextile is made from strong, durable, non-woven polypropylene (Soil retention filter O90=<80µm) having a very high permeability (Discharge capacity at 300 kPa i=0.1 > 80x10-6 m³/s). For the modification, two flat steel bars were installed on both sides of the core inside the wick drain. Thus two technics can be used as a single product. The width of the wick drain (modified and original) is about 4 inches, and the thickness is ≥3mm.

In this study, six pools with the dimensions of 3.88m x 2.96m and the depth of 2.3m were used. These pools were filled with iron tailing that was taken from the thickener in the form of slurry up to the depth of 1.8m. The dry tailing was tested for soil classification, and the tailing was ML (Silt). The particle distribution is shown in figure 2:

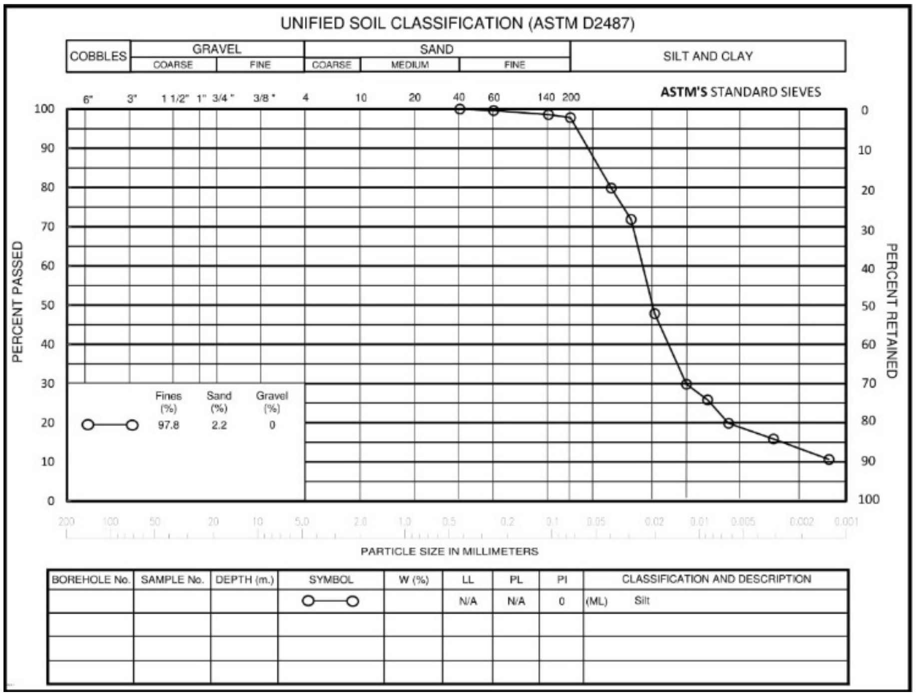

Figure 2. Unified soil classification curve of the tailing used in this research.

After filling the pools, the new drainage product (electrode and Wick drain) and electrodes installed by hand in the pools with the pattern shows in figure 3. Then it was given one day of setting time, and the excess water that was accumulated on top was removed by siphon.

The arrangement of the pools and electrodes were as follows:

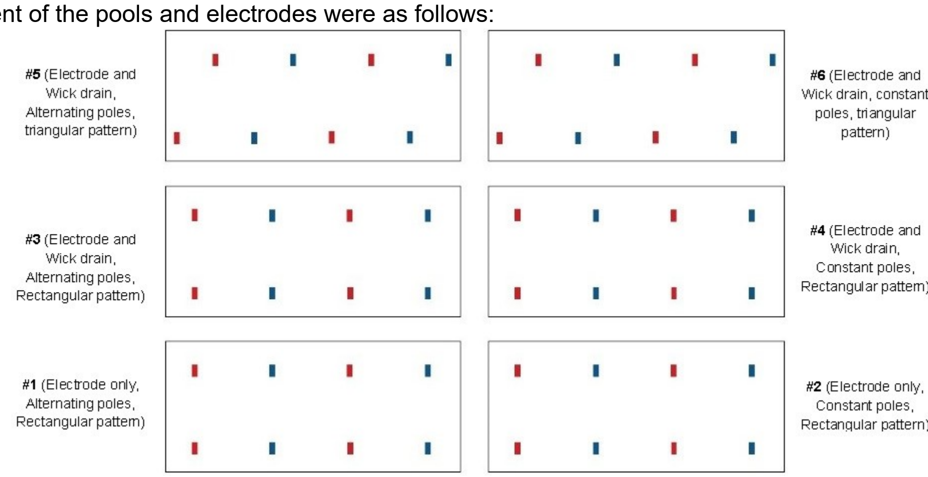

Figure 3. The pattern of treatment in the pools.

As can be seen in the picture, the pattern in pools #1, 2, 3, and 4 is square, and the pattern in pool #5 and 6 is triangular. The blue electrodes are cathodes, and the red electrodes are anodes that can be seen in figure 2. Poles in pools #2, 4, and 6 were alternated on each day. Also, pool #1 and 2 had only electrodes, while the combination of Wick drains and the electrode was used in the other pools. With this installation, a complete comparison can be made about the effect of the pattern, alternating poles and constant poles, and also the new product with the electrodes only.

For the power supply, a DC rectifier with a voltage of 48V was used, and the spacing between electrodes was 1m. So, the voltage gradient was 48V/m. Figure 4 shows the way the new drainage products has installed in pool #4. Red cable was used to connect anodes, and blue cable was used to connect cathodes to the electrical power source.

Figure 4. New drainage product installed in pool number 4

4. MOISTURE CONTENT TEST

At the beginning of the test, the solid content of the slurry was about 50%. Since the tailing samples were taken from the thickener, they had coagulant in them, and after one day as setting time, the solid portion of the tailing, settled, and the clear water of the top siphoned out. After the setting time and during the test, the slurry became like a paste, and then every day, a soil sample was taken for moisture content measurement. The samples were taken from the surface, from the vicinity of each electrode with the same distance from each electrode to make them comparable with each other. It should be noted that after the first few days of the test, there was no free water on the surface to be siphoned. Actually, the water came up and mostly evaporated. The results of moisture vs. time are shown in figures 5 to 6. It was tried to take the samples from the same radius from similar electrodes to make them comparable. Fluctuation can be seen in the diagram, but the total trend is visible in the charts. The fluctuation was also reported by Barooti et al. (2019) and with a smoother movement by Lemond-Black et al. (2005).

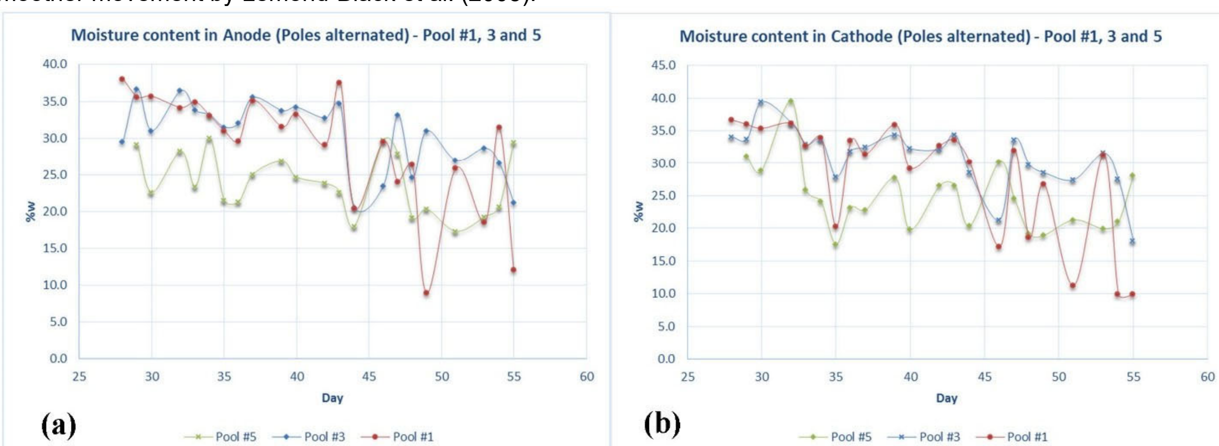

Figure 5. (a) Moisture content in Anode-Pool #1, 3, and 5, (b) Moisture content in Cathode-Pool #1, 3, and 5.

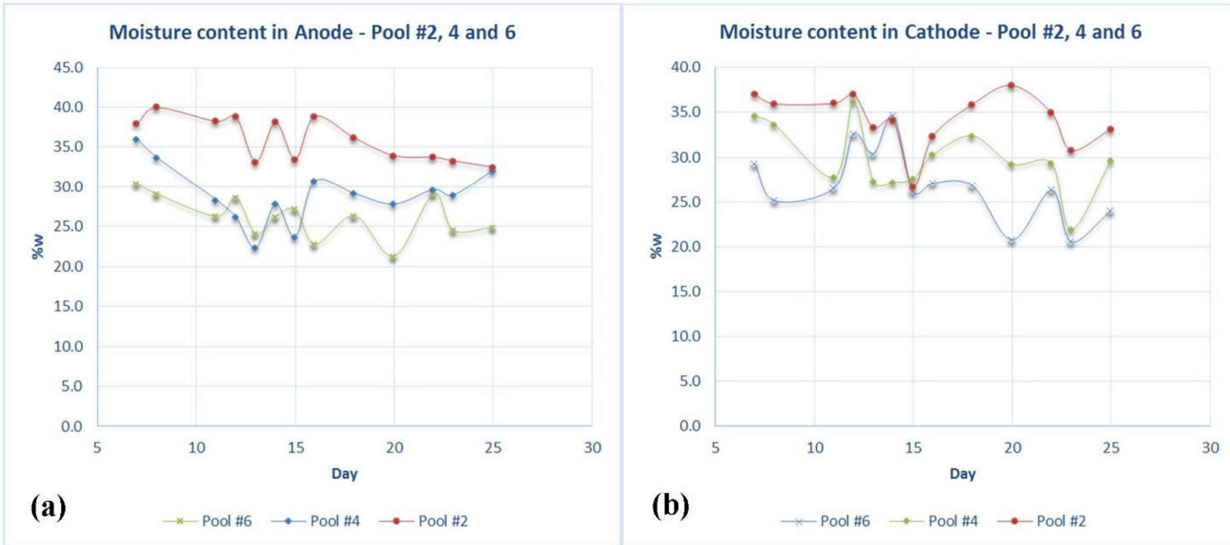

Figure 6. (a) Moisture content in Anode-Pool #2, 4, and 6, (b) Moisture content in Cathode-Pool #2, 4, and 6.

Two test pits were dug in each pool, and samples were taken every 20cm to measure the moisture content to check the moisture content at different depths. Test pits were excavated in the middle of the electrodes. The results can be seen in figures 7 and 8. The words of “red” and “blue” are used to distinguish between anode and cathode; however, in the pools that the poles alternated, there is no difference between poles (i.e., pool 1,3 and 5).

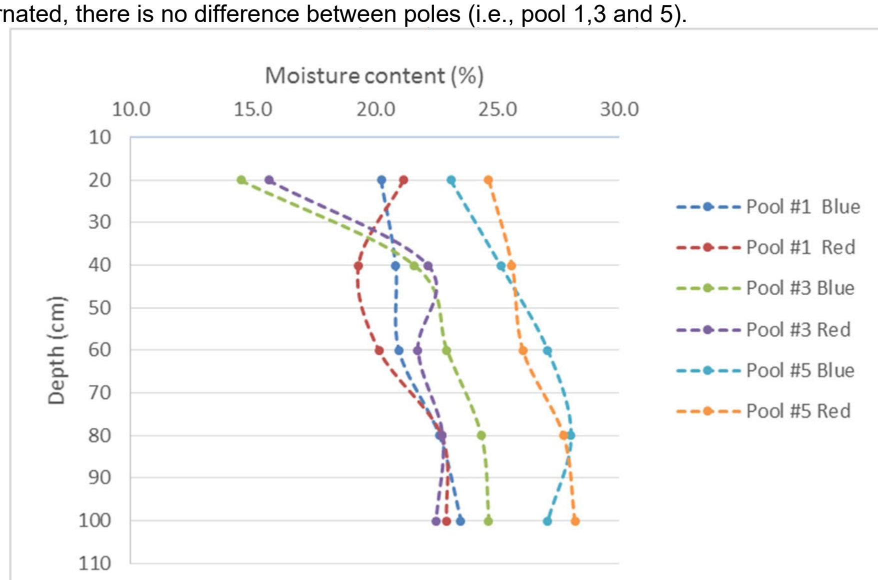

Figure 7. Moisture content in depth-Pool #1, 3, and 5

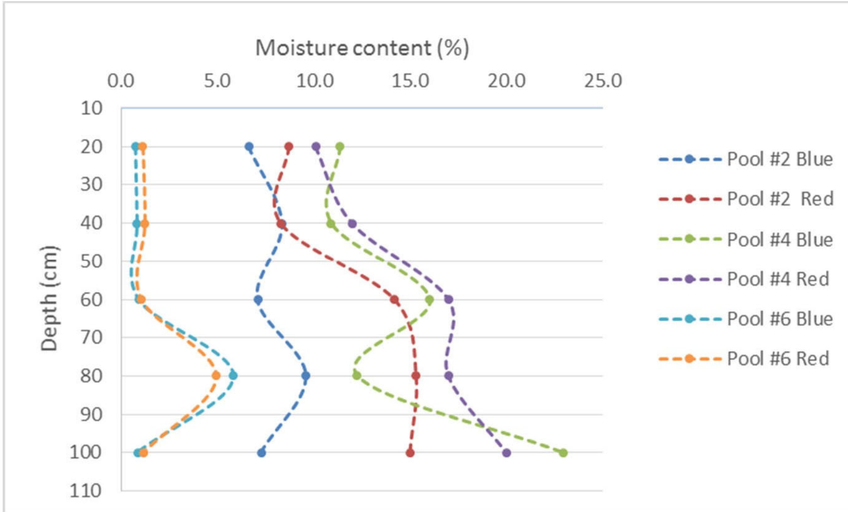

Figure 8. Moisture content in depth-Pool #2, 4 and 6

5. ANALYSIS OF THE RESULTS

In pools #1, 3, and 5, where poles were alternated, reduction of the moisture that was measured beside the electrodes on the surface was more than pools with constant poles. In general, the drop was around 5% only, and the moisture content in the anode and cathode side was almost the same as before.
As can be seen in figures 7 and 8, generally, the moisture content increased by the depth. Another critical point is that the results that were shown in figures 7 and 8 show lower total moisture in pools #2, 4, and 6, which is the opposite of the results of moisture content on the surface. The reason is that during the test, samples were taken from around the electrodes on the surface that were always wet. This shows that the combination of electrodes and wick drain worked well to bring the water to the surface. On the other hand, it shows that relying only on the moisture content of the samples taken from the proximity of each electrode is not representative of the whole situation.
For this reason, studying the moisture in different depths in the middle of two electrodes is essential for a correct conclusion. The reduction in pool #6 was better in different depths (triangle pattern). In the pools with changing poles, the square pattern showed a better result (pools #3 and 5). Lemont-Black et al. (2005) compared a rectangular pattern with a hexagonal pattern, and he showed that the total moisture content reduced more in a hexagonal pattern.

6. CONCLUSION

Wick-drain and electrodes combined to make a new product to use both techniques at the same time for dewatering. The subjected soil was iron mine tailing that was classified as silt (ML). The moisture content in the pools where the direct current alternated was reduced by about 5% near the electrodes. The maximum reductions observed in the pools where constant poles were used were 70% in pools #1 and 40% in pool #3. After studying the moisture at different depths, between the electrodes, it was observed that the moisture content is increased by depth. The reduction of moisture content in different depths was more significant in pools #2, 4, and 6 and is the opposite of what was observed near the electrodes on the surface. The reason is that in constant poles, the water accumulated near the electrodes. It was observed that in the pools that constant poles were used, the total moisture content was reduced more in the middle of electrodes. The best results were for pool #6, in which the combined method (i.e., electrodes and wick drain) was used, and the poles were constant.

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