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The Physical Behavior of Stabilised Soft Clay by Electrokinetic Stabilisation Technology

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Abstract. Electrokinetic Stabilisation (EKS) technology is the combination processes of electroosmosis and chemical grouting. This technique is most effective in silty and clayey soils where the hydraulic conductivity is very low. Stabilising agents will assist the EKS treatment by inducing it into soil under direct current. The movement of stabilising agents into soil is governed by the principle of electrokinetics. The aim of this study is to evaluate the physical behavior of soft soil using the EKS technology as an effective method to strengthen soft clay soils with calcium chloride (CaCl₂) as the stabilising agent. Stainless steel plates were used as the electrodes, while 1.0 mol/l of CaCl₂ was used as the electrolyte that fed at the anode compartment. Soft marine clay at Universiti Tun Hussein Onn Malaysia was used as the soil sample. The EKS treatment was developed at Research Centre for Soft Soil (RECESS), UTHM with a constant voltage gradient (50 V/m) in 21 days. The result shows that the shear strength of treated soil was increased across the soil sample. The treated soil near the cathode showed the highest value of shear strength (24.5 – 33 kPa) compared with the anode and in the middle of the soil sample.

1. Introduction
The main problems that faced in construction are the low permeability, low strength and low bearing capacity on soft soil. In a certain condition, the soil or fill material cannot reach the required specification in geotechnical aspect and need to be improved [1,2,3]. There are two options to enhance the ground improvement, either by physical or chemical stabilisation [4,5,6, 7]. Ground improvements are important in construction so that loads can be applied without causing failure of collapse, settle or failure cause of bearing capacity. EKS is the one of the principles of chemical stabilisation and has been chosen as potentially the best method to enhance the improvement of the soft soil [8,9]. It shows that this method can be less expensive compared to other method[10,11,12,13], furthermore this method also have advantage by not disturbing site activities [14]. The aim of this research is to evaluate the use of EKS as an effective method to strengthen UTHM soft clay soils. This research study was conducted in Research Centre for Soft Soils (RECESS) of Faculty of Civil & Environmental Engineering, UTHM. Soft marine clay was used as the sample and small scale laboratory setup for this research is shown in Fig.2.

2. Methodology
The laboratory scale container for EKS testing was designed for this research. A schematic diagram of the laboratory scale container is shown in Fig.1. The container was made by transparent acrylics plate with 420 mm depth, 170 mm width and 358 mm length. The thickness of the acrylics plate was 15 mm. The transparent acrylics plate for the laboratory scale container was used to prevent short
circuiting, monitoring the soil level during consolidation and monitoring the level of water and chemical solution.

The container consisted of three chambers, which were separated with perforated walls. The soil sample was then placed into the main compartment and the two small compartments were used to supply the chemical stabilisers into the soil.

![Schematic diagram of EKS laboratory scale container.](image)

**Figure 1.** Schematic diagram of EKS laboratory scale container.

There were two different detachable bases (solid and perforated bases). The holes of perforated walls and base were 5 mm in diameter and the spacing between the holes was 17 mm centre to centre (see Fig. 2). The purpose of perforated base is to enable drainage of water from main compartment during consolidation while the solid base was grooved to discharge water at the edge of the tank to a volume measuring tube.
Filter papers were attached at both perforated sides of wall and perforated base from inside the main compartment to prevent soil particles movement into the electrode chambers. During consolidation, solid acrylics plates of 3 mm thick were used at both sides of filter systems to ensure drainage of water only occurred at the top and bottom of the soil. A steel loading plate was placed on top of the sample in the main compartment to ensure the loads were uniformly distributed to the soil sample [4,8,15].

The steel loading plate was designed with twelve holes (10 mm diameter) to allow drainage at the top. The plate was covered with polystyrene to avoid direct contact of steel plate and the soil. The holes of the polystyrene were made at same position with the holes of the plate to avoid blocking of water during consolidation.

After completed the consolidation stage, the 3 mm solid acrylics plates were carefully removed from the container. After consolidation stage of the soil ended, the perforated base was changed to the solid base. Electrode, electrolyte and stainless steel wire were placed as shown in Fig. 2 for the treatment stage. A 1.0 mol/l of CaCl$_2$ solution was fed at the anode compartment while distilled water (DW) was fed at the cathode compartment. A constant voltage gradient (50 V/m) was applied to the soil sample to transport calcium ions from the anode towards the cathode. EKS treatment was performed for 21 days period of time. The weight of the electrodes were measured before and after treatment to check the weight loss that caused by corrosion of the electrodes.

2.1 Sample preparation
Soil samples were dried in the oven for 24 hours. The dried sample was ground using grinder machine to get very fine material that would pass 425 µm sieve. The slurry sample was prepared by mixing the soil samples about 14.05 kg with 12.08 kg distilled water to achieved 86% water content. The water content of slurry was chosen based on 1.5 times liquid limit (LL). The slurry sample was mixed using mechanical mixer and blended thoroughly for 30 minutes. Then, the slurry sample was placed inside
the main compartment and was left overnight to ensure homogeneity. Uniformly distributed load was applied to the slurry sample by using large strain consolidation to reduce the water content.

2.2 Monitoring of EKS testing
The values of current, anolyte and catholyte solutions were monitored along the 21 days of treatment. The amount of effluent water from the Mariotte bottles and effluent water from measuring cylinder were monitored over the same period of time. At the first day of the treatment, the reading of current value was taken at 1, 2, 4, 6 and 8 hours. At the second day and afterward, the reading of current value, volume of anolyte and catholyte solutions, and effluent water from measuring cylinder were taken every 24 hours.

2.3 Laboratory testing of treated soil
The treated soils after EKS treatment were investigated through their physical and chemical characteristics. The soils were divided into 3 sections which were near the cathode, in the middle and near the anode. The layers were divided at the bottom (0 – 80 mm), in the middle (81 – 160 mm) and at the top (161 – 240 mm) at each sections. This was performed for repeatability test and to know the effects and efficiency of the treatment.

2.4 Test for treated soil
Atterberg limit, moisture content, and vane shear testing were performed to determine the physical properties of the treated soil. For Atterberg limit test, liquid limit test is in accordance to BS 1377 Part 2: 1990: 4.3 and plastic limit test is in accordance to BS 1377 Part 2: 1990: 5. For liquid limit test, the wet soils from the tank were not oven dried because it may affect the soil properties due to the high temperature. While for plastic limit test, it is possible to dry using oven before the test will be performed. Moisture content for treated soils was determined in accordance to BS 1377 Part 2: 1990: 3.2. The treated soil that attached on the vane blade after conducting hand vane shear test was taken immediately for moisture content determination. Hand vane shear test was performed because the size of the treated soil samples in the tank would be too small to be determined by another methods. This test was performed immediately after EKS treatment ended. For chemical properties, pH testing was conducted for treated soil. Each sample for treated soil was performed at different sections as same as physical properties testing.

3. Results and discussion

3.1 Monitoring data
Table 1 shows the amount of addition and effluent of CaCl₂ and DW for 21 days treatment. It shows that there was no amount of effluent from CaCl₂. While for DW, the amount of addition was only at the first day treatment and the amount of effluent were started from second day and afterward. The current values that were applied to the treatment were in the range of 47.46 – 48.54 V/m.
### Table 1. Monitoring data

| Day | Addition of CaCl₂ (ml) | Effluent of CaCl₂ (ml) | Addition of DW (ml) | Effluent of DW (ml) |
|-----|------------------------|------------------------|---------------------|---------------------|
| 1   | 1820                   | -                      | 1705                | -                   |
| 2   | 400                    | -                      | -                   | 470                 |
| 3   | 400                    | -                      | -                   | 380                 |
| 4   | 330                    | -                      | -                   | 280                 |
| 5   | 400                    | -                      | -                   | 320                 |
| 6   | 265                    | -                      | -                   | 280                 |
| 7   | 280                    | -                      | -                   | 240                 |
| 8   | 230                    | -                      | -                   | 155                 |
| 9   | 195                    | -                      | -                   | 130                 |
| 10  | 110                    | -                      | -                   | 80                  |
| 11  | 150                    | -                      | -                   | 100                 |
| 12  | 145                    | -                      | -                   | 100                 |
| 13  | 180                    | -                      | -                   | 120                 |
| 14  | 170                    | -                      | -                   | 140                 |
| 15  | 190                    | -                      | -                   | 150                 |
| 16  | 135                    | -                      | -                   | 150                 |
| 17  | 165                    | -                      | -                   | 100                 |
| 18  | 155                    | -                      | -                   | 120                 |
| 19  | 160                    | -                      | -                   | 130                 |
| 20  | 150                    | -                      | -                   | 120                 |
| 21  | 145                    | -                      | -                   | 130                 |

### 3.2 Soil classification

Table 2 shows the result of soil classification. The plastic limit for soft clay was 36.07 % and the liquid limit was 60.84 %. The percentage of liquid limit was in the range of 30 – 110 % and plastic limit was in the range of 25 – 40 %, thus can be considered as kaolinite soil. The results of plastic index, specific gravity and pH value were 24.77 %, 2.60 and 2.73 (acidic), respectively. Generally, the soil classification values of the soil sample were similar as reported by Abdurahman [1]. The results were reported that plastic limit, liquid limit, plastic index and specific gravity value were 20 – 35 %, 37 – 65 %, 13 – 31 % and 2.18 – 2.65, respectively.

| Parameter          | Results  |
|--------------------|----------|
| Plastic limit      | 36.07 %  |
| Liquid limit       | 60.84%   |
| Plastic index      | 24.77%   |
| Specific gravity   | 2.60     |
| pH                 | 2.73     |

### 3.3 Atterberg Limit

Fig. 3 shows the liquid limit values of treated soft clay and untreated soft clay as the control value (60.84 %). The 21 days EKS treatment shows that lowest value of 49.65 % was at 45 mm from anode and it increased to 52.98 % at the middle point (135 mm from anode). The highest value of liquid limit for treated soft clay was at cathode section (225 mm from anode) with 62.45 %. The distribution of liquid limit values have a similar trend with Ahmad Tajudin [4], where the lowest liquid limit value was occurred at the anode and the value was slightly increased to the cathode.

Fig. 4 shows the plastic limit values for treated soft clay and untreated soft clay as control line. The profile shows the treated soft clay lie below the control line (36.07 %). At 45 mm from anode the plastic limit was 35.43 %. It shows the value drop at the middle (135 mm from anode) with 34.34 % and at the cathode (225 mm from anode) the plastic limit was 35.05 %. According to Ahmad Tajudin [4], the trend of plastic limit distribution lie below the control line for only at the anode and the middle. At the cathode, the plastic limit value was different with the previous researcher but the value still in the range at about 25 – 40 %.

Fig. 5 shows the plasticity index values for CaCl₂-DW (21 days) system and untreated soft clay as the control value (24.77 %). It shows that only value at cathode (225 mm from anode) lie above the
control values with 27.04 %. The lowest value was at 45 mm from anode with 14.22 % and it increased at the middle (135 mm from anode) with 18.61 %. This distribution of plastic index values shows the different trend with Ahmad Tajudin [4], but these values were closed at the range of 16 – 24 %.

Figure 3. Liquid limit of CaCl₂-DW system with distance from anode

Figure 4. Plastic limit of CaCl₂-DW system with distance from anode

Figure 5. Plasticity index of CaCl₂-DW system with distance from anode
3.4 Shear strength

Fig. 6 shows the profiles of shear strength values of soft clay. These values consist of values of treated soft clay after EKS which were taken at three different depth and the values of untreated soft clay as the control line.

The 21 days EKS treatment shows the greatest improvement compared to the untreated soft clay. The strength values of treated soft clays were between 10 to 33 kPa that were increased above the control line. It shows that the highest strengths of treated soft clay were occurred at 270 mm from anode. Probably that might cause from precipitation due to the cementitous gel and water content [14,19].

At top (161 – 240 mm), from 30 to 120 mm from anode the strength values were constant at 12 kPa while the strength were increased from 150 to 270 mm from anode with the highest strength value of 24.5 kPa. At the middle (81 – 160 mm), the strength were slightly increased from 30 to 120 mm from anode but the value were reduced to about 11 kPa at 180 mm from anode. However, the strengths were increased from 210 until 270 mm from anode with the highest strength value of 26 kPa. At bottom (0 – 80 mm), it shows the strength were reduced at 120 mm from anode with 10 kPa and were slightly increased to 33 kPa at 270 mm from anode.

The strength variations with distance from anode have similar trend as reported from Ahmad Tajudin [4], where the same type of chemical stabilisers were used except with the highest value that were occurred at the cathode. This probably because the different between the duration of treatment, type of electrodes were used and where the electrodes were placed. As compared to Liaki [16], the strength variations have the lowest value at the cathode where stainless steel have been used as the electrodes but without the stabilisers added. This is clearly shows that the addition of stabilizing agent has improved the soil after the treatment hence increased the shear strength of soil as reported by other researchers [14,15,20].

![Figure 6. Shear strength of CaCl₂-DW system with distance from anode](image)

3.5 Water content

From Fig. 7, the water content for treated soft clay after 21 days EKS treatment were slightly below the control line (untreated). The soil profile shows that the water content values which were taken at three different depth were quite similar at the anode (30 to 90 mm from anode) and the cathode (240 to 270 mm from anode) except at the middle section (120 to 210 mm from anode). The water content values for treated soft clay were in the range of 44% to 55.24%. It also shows that at the cathode (270 mm from anode) the water content seem close to the untreated value. The differ value of moisture content for three different depth probably due to the electroosmotic flow induced by the electric field from electrokinetic process during EKS treatment [16,17,18,19].
At the top (161 – 240 mm), the lowest water content was at 60 mm from anode with 44.94% and the highest water content was at near cathode section (240 mm from anode) with 52.95%. At the middle (81 – 160 mm), the lowest water content was at 60 mm from anode with 44.71% and the highest water content was at 150 mm from anode with 55.24%. While at the bottom (0 – 80 mm), the lowest water content was at 60 mm from anode with 44% and the highest water content was at cathode section (270 mm from anode) with 54.85%.

The water content variations with distance from anode have a different trend as reported by Liaki [17], where the data lie above of the control line with the highest water content at about 75 – 875%.

![Figure 7. Water content of CaCl$_2$-DW system with distance from anode](image)

### 3.6 pH

Fig. 8 presents the results of pH distribution of CaCl$_2$-DW (21 days) treated soft clay and the untreated pH value for the soft clay as control line. The actual pH value of the soft clay of untreated soil was 2.73. Generally, the profile shows the pH for treated soft clay increased from anode to the cathode. At the middle, pH value seems closed with control line with pH 2.8. At 45 mm from anode the pH is highly acidic (pH 1.7). The low acidic condition was at the cathode (225 mm from anode) with pH 5.3. The increase of pH values near the cathode is due electrolysis process which produces the hydroxide ions.

The pH variations with distance from anode have a similar trend as reported by Ahmad Tajudin [4], where at the anode the pH lie below the control line, at the middle the pH seem close with the control line and at the cathode the pH was increased and lie above the control line. Compared to Liaki [16,17], if the treatment have no addition of stabiliser it gave the highest value of pH about 8 – 9 at the cathode.
4. Conclusion
EKS treatment was conducted on UTHM soft clay by using calcium chloride as the electrolyte and stainless steel as the electrode. The treatment was running for 21 days and a constant voltage gradient of 50 V/m was applied to the soil. The introduction of highly alkaline calcium chloride solution from the anode compartment into the soil sample has significantly increased the strength of the treated especially in the vicinity of the cathode. Nevertheless, EKS treatment of soft clay has reduced soil water content due to the electroosmosis process during the EK treatment which caused an increase of soil pore water pressure, thus increased the shear strength of soil.

As a conclusion, the addition of highly alkaline calcium chloride into the system decreased the liquid limit and plastic limit of soft clay. This is due to the high acidic environment after the treatment. Regarding the pH values of treated soil it shows that CaCl₂-DW system to the soft clay creating an acidic value at the anode and slightly increased to base value to the cathode.

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References
[1] Abdurahman, M N, (2005) Short term performance evaluation of a rural road embankment with different reinforcement constructed on soft soil pertaining to vertical settlement. Master of civil engineering, KUiTTHO.
[2] Acar, Y B & Alshawabkeh, A N, (1993) Principles of Electrokinetic Remediation. Environmental Science and Technology, 2638-2647.
[3] Ahmad K.Taha M R,Kassim K A, (2011) Electrokinetic treatment on a tropical residual soil.Institution of Civil Engineers, ICE, 1-11.
[4] Ahmad Tajudin, S A, (2012) Electrokinetic Stabilisation of Soft Clay. School of Civil Engineering, University of Birmingham, UK.
[5] Azmi M A M, Tajudin S A A, Shahidan S Masrom M A N & Nabila A T A (2016) Preliminary Study on Remediation of Contaminated Clay Soil Using Cement and Sugarcane Bagasse, IOP Conference Series: Materials Science and Engineering, 103, 07001
[6] Azhar, A.T.S., Hazreek, Z.A.M., Aziman, M., Haimi, D.S., Hafiz, Z.M. (2016) Acidic Barren Slope Profiling using Electrical Resistivity Imaging (ERI) at Ayer Hitam area Johor, Malaysia, Journal of Physics: Conference Series 710 (1), 12008.
[7] Tajudin S A A, Mohammad Azmi M A, Shahidan S, Abidin M H Z, Madun A, (2016) Relationship of physical parameters in Pb-contaminated by stabilization/solidification method, MATEC Web of Conferences 47, 03015.

[8] Tajudin S A A, Nordin N S, Marto A, Madun A, Abidin M H Z, Jefferson I, Azmi M A M, (2016) The monitoring and cementation behavior of electrokinetic stabilisation technique on Batu Pahat marine clay” International Journal of GEOMATE 11 (4) 2581-2588.

[9] Embong Z, Jamari S, Mohamed Johar S, Ahmad Tajudin S A, (2015) The assessment of heavy metal concentration in river bank soil under the effect of electrokinetic-assisted phytoremediation using XRF and EDX analysis, Jurnal Teknologi 77 (30) 133-137.

[10] Pakir F, Marto A, Yunus N Z M, Tajudin S A A, Tan C S, (2015) Effect of sodium silicate as liquid based stabilizer on shear strength of marine clay, Jurnal Teknologi 76 (2) 45-50.

[11] Tajudin, S.A.A., Marto, A., Azmi, M.A.M., Madun, A., Abidin, M.H.Z. (2015) “Utilization of sugarcane Bagasse ash for stabilization/solidification of lead-contaminated soils” Jurnal Teknologi 77 (11), pp. 119-125

[12] Aziman, M., Hazreek, Z.A.M., Azhar, A.T.S., Haimi, D.S. (2016) “Compressive and Shear Wave Velocity Profiles using Seismic Refraction Technique” Journal of Physics: Conference Series, 710 (1), 12011

[13] Ali, A. (2004) Metal removal from soil by electrokinetic processes: the effects of inorganic soil components on the process. Brighton.

[14] Asavadorneja, P., Clawe, U. (2005) Electrokinetic Strengthening of Soft Clay Using the Anode Depolarization Method. Bull Eng. Geol Environ, pp. 237-245.

[15] Barker, J.E., Rogers, C.D.F., Bordman, D.I., Peterson, J. (2004) Electrokinetic stabilisation: an overview and case study. Ground Improvement, pp. 47-58.

[16] Liaki, C. (2006) Physicochemical study of electrokinetically treated clay soils using carbon and steel electrodes. School of Civil Engineering, University of Birmingham, UK.

[17] Liaki, C., Rogers, C.D.F., Boardman, D.I. (2010) Physico-chemical effects on clay due to electromigration using stainless steel electrodes. J Appl Electrochem, pp. 1225-1237.

[18] Mitchell, J. K., Soga, (2005) K. Fundamentals of Soil Behavior. 3rd ed. Berkeley: University of California.

[19] Azhar, A.T.S., Nabila, A.T.A., Nurshuaila, M.S., Azim, M.A.M., & Zahin, A.M.F. (2016) “Novel Technique to improve the pH of Acidic Barren Soil using Electrokinetic-bioremediation with the application of Vetiver Grass” IOP Conference Series: Materials Science and Engineering,160(1), 012076.

[20] Tajudin, S.A.A., Azmi M.A.M & Nabila A.T.A (2016) Stabilization/Solidification Remediation Method for Contaminated Soil: A Review, IOP Conference Series: Materials Science and Engineering,136(1), 012043.