Effect of Calcium and Sodium Ions in Soft Clay Using Electrokinetic Stabilisation Technique

Nurul Syakeera Binti Nordin[1,a], Saiful Azhar Bin Ahmad Tajudin[2,b], Aeslina Binti Abdul Kadir[3,c], Fajaruddin Bin Mustakim[4,d], Mohamad Azim Bin Mohammad Azmi[5,e] and Mohamed Nur Shafiq Bin Mohamed Hanif[6,f]

[1,2,3,4,5,6] Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400, Parit Raja, Batu Pahat, Johor, Malaysia

[a]gf120033@siswa.uthm.edu.my, [b]saifulaz@uthm.edu.my, [c]aeslina@uthm.edu.my, [d]fajardin@uthm.edu.my, [e]mohamadazimazmi@gmail.com, [f]mohamednurshafiqmohamedhanif@gmail.com

Keywords: electrokinetic stabilisation technique, soft clay, calcium, sodium, stainless steel.

Abtract. Electrokinetic Stabilisation (EKS) technique is the combination processes of electroosmosis and chemical grouting. This study involves investigating on the performance of EKS technique to stabilise the soft clay soils. Stabilising agents will assist the EKS technique by inducing it into soil under direct current and its movement is governed by the principle of electrokinetic (EK). The objective of this research is to study the effectiveness of EKS technique to increase the strength of soft clays. Two reactors were set up by using 1.0 M of calcium chloride ($CaCl_2$) and sodium silicate (Na_2SiO_3) as the electrolyte, and stainless steel plates as the electrodes. EKS technique was performed in 21 days period of time with a constant voltage gradient (50 V/m). This technique is carried out in two phases where the difference between them is a combination of the stabilising agent. The difference combination of stabilising agents between phase 1 and phase 2 were $CaCl_2$ – distilled water (DW) and $CaCl_2$ – Na_2SiO_3, respectively. The results of strength, liquid limit (LL), plastic limit (PL), plastic index (PI), pH and ion concentration test towards untreated and treated soil is presented. Showing the strength of treated soil for both phases were increased near the cathode section with 27.83 kPa and 27.67 kPa. LL and PI for treated soil showing the highest value were occurred near the cathode, while PL seems consistant with values from untreated soil. Calcium (Ca^+) and sodium (Na^+) concentrations in soil showing it were increased compared to untreated soil, hence it proved that the application of stabilisers in EK treatment is more effective in increasing the strength and the stability of soils.

Background

EKS is the combination process of electroosmosis and chemical grouting and it is most effective for silty and clayey soils because of its low hydraulic conductivity [2]. Basically this technique is to improve the volume stability of soil around and beneath the foundation. This technique involves applying an electrical current across the soil mass to boost the chemical migrates from the injection point with the purpose of reacting beneficially with the soil to bring about an improvement in its properties. The advantage by using EKS instead of traditional mix-in-place chemical stabilisation is that the technique allows for remote treatment through soil without any excavation works [2]. The EKS technique can be enhanced by the use of some non-toxic stabilising agents such as lime or calcium chloride solutions. These chemical solutions can be fed at the anode or the cathode depending on the ions to be transferred into the soil. The addition of these chemical stabilisers will alter some properties of the soil such as texture, plasticity, compressibility and permeability. Hence, it can be very effective in improving soil characteristics by reducing the amount of clay size particles and increasing the shear strength [5].

Method and Material

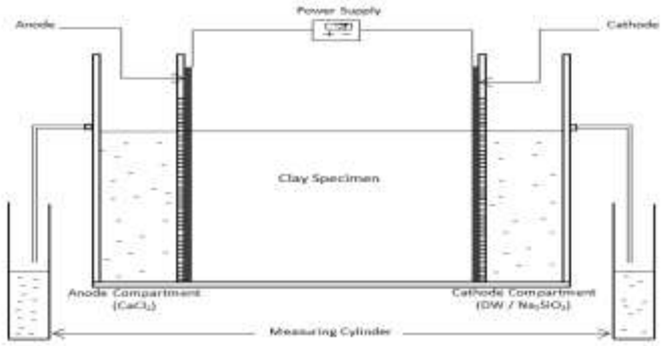

Fig. 1 Schematic diagram of EKS test rig

The EKS test rig was designed for this research. Electrode, electrolyte and stainless steel plate were placed as shown in Fig. 1. For the first phase ($CaCl_2$ – DW), 1.0 M of $CaCl_2$ solution and DW were fed at the anode and cathode compartment, respectively. While 1.0 M of $CaCl_2$ and Na_2SiO_3 solution were fed at the anode and cathode compartment, respectively in the second phase ($CaCl_2$ - Na_2SiO_3). A constant voltage gradient (50 V/m) was applied to the soil sample as suggested by Mitchell & Soga [3] and experiment was performed for 21 days period of time. 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 with distilled water to achieve 90 % of water content. The water content of slurry was chosen based on 1.5 times liquid limit (LL). Then, the slurry sample was placed inside the main compartment (278 x 165 x 413) mm and uniformly distributed load was applied to it by using large strain consolidation to reduce the water content hence make it in fully saturated condition [6-8]. Hand vane shear test has been used to determine undrained shear strength of soil. For LL and PL it were referred to BS 1377 Part 2:1990, while pH was referred to BS Part 3:1990. In determination of ion concentration, atomic absorption analysis was applied to the soil sample by referred to toxicity characteristic leaching procedure method (EPA Test Method 1311).

Soil Classification of Untreated Soil

Table 1 shows the current results and results from previous study of soil classification for untreated soft marine clay at Parit Raja. It shows that those current results were in range and similar as reported by Abdurahman [4]. Mitchell and Soga [3] mentioned that if the plastic and liquid limit of soil were in range 25 – 40 % and 30 – 110 % it considered as kaolinite soil.

Table 1 Soil classification of untreated soil

Soil classification	Current results	Results from previous study
Plastic limit	36.07 %	20 – 35 %
Liquid limit	60.84 %	37 – 65 %
Plastic index	24.77 %	13 – 31 %
Specific gravity	2.60	2.18 – 2.65
pH	2.73	-

Results for Treated Soil

The profiles of the average shear strength of treated soil were shown in Fig. 2. It consist of shear strength values of untreated and treated soil for both phases and it shows the trend of strength value for treated sample lie above the control line. The highest strength values were occurred near the cathode section (270 mm from anode). This is probably caused by effect from precipitation of the cementatious gel and water content at the area. The strength variations for $CaCl_2$ - Na_2SiO_3 have a similar trend as reported from Ahmad Tajudin [8], where the highest value occurred near the cathode section. The profiles were different compared to Liaki [1], where the lowest strength value occurred near the cathode section. This is because no stabilisers has been applied to EKS technique in previous study and it clearly shows that the addition of stabilisers has improved the soil characteristic hence increased the shear strength of soil.

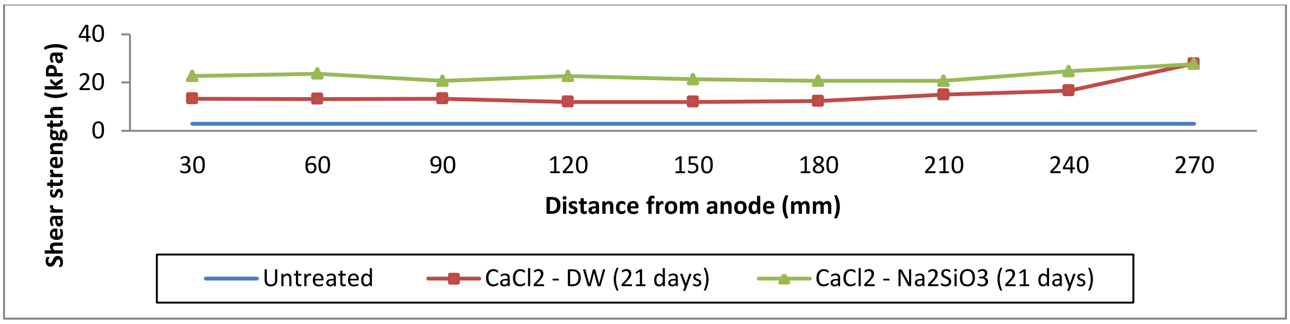

Fig. 2 Shear strength with distance from anode

Table 2 Shear strength for treated soil

Dist. from anode (mm)	30	60	90	120	150	180	210	240	270
C_u, (kPa) $_{CaCl2-DW}$	13.33	13.17	13.33	12.00	12.00	12.33	15.00	16.67	27.83
C_u, (kPa) $_{CaCl2-Na2SiO3}$	22.67	23.67	20.67	22.67	21.33	20.67	20.67	24.67	27.67

The profiles of liquid limit in Fig. 3 shows the lowest value were at 45 mm from anode and the highest value were at 225 mm from anode for both phases. The distribution have a similar trend as reported by Ahmad Tajudin [8], where the lowest liquid limit value was occurred near the anode section and the values were slightly increased towards the cathode. The profiles of plastic limit were shown in Fig. 4. The treated soft clay for both phases seems lie below the control line. It shows the value were decreased at the middle (135 mm from anode) for both phases. According to Ahmad Tajudin [8], the trend of plastic limit distribution lie below the control line for only near the anode and the middle section. At 225 mm from anode, the trend value was different with previous researcher but the value still in range at about 25 – 40 %.

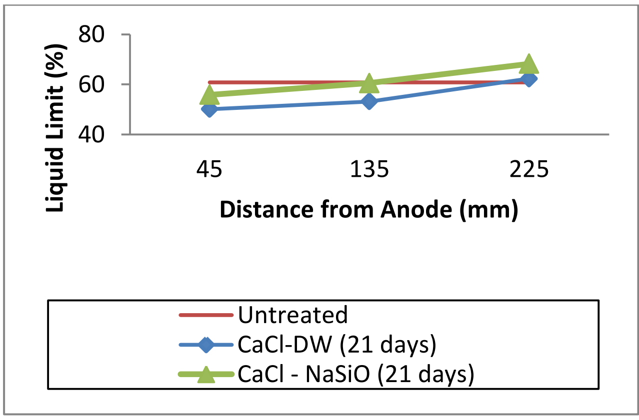

Fig. 3 Liquid limit with distance from anode

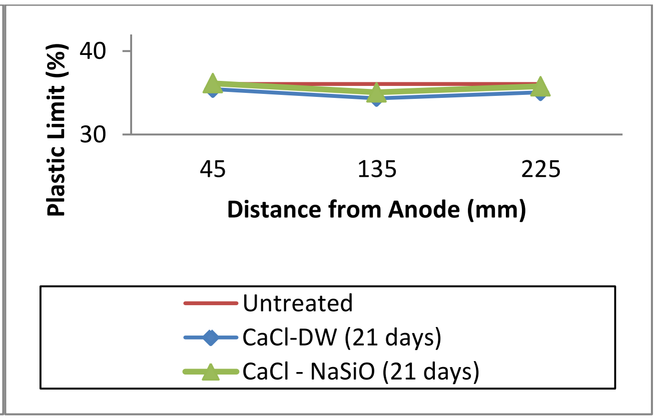

Fig.4 Plastic limit with distance from anode

Fig. 5 shows the plastic index values and it shows that only value at 225 mm from anode lie above the control line for both phases. While, the lowest value for both phases were occurred at 45 mm from anode. The distribution shows the different trend with Ahmad Tajudin [8], but these values seems closed at the range of 16 – 24 % as reported by the researcher. Fig. 6 presents the results of pH values and he profile shows the values were increased from anode to the cathode. At 45 mm from anode, pH value for both phases considered as highly acidic. The lowest acidic condition for both phases were occurred near the cathode (225 mm from anode). The increment of pH values near the cathode possibly due to electrolysis process which produces the hydroxide ions. Those variations have a similar trend as reported by Ahmad Tajudin [8], where near the anode the pH value recorded as the lowest value but slightly increased towards the cathode. If no addition of stabiliser applied in EK technique as reported by Liaki [1], the highest value of pH of treated soil will be occurred near the cathode section with pH 8 – 9.

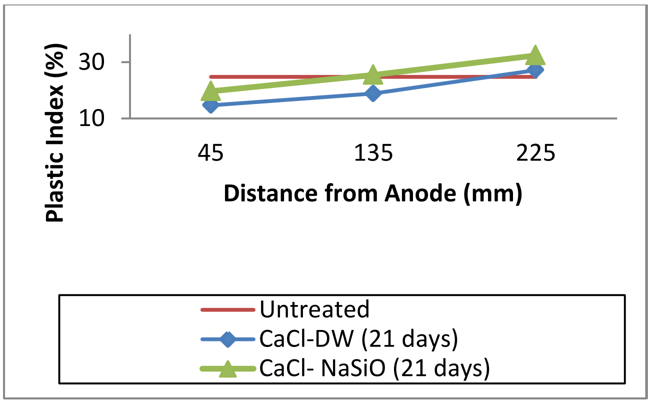

Fig. 5 Plastic index with distance from anode

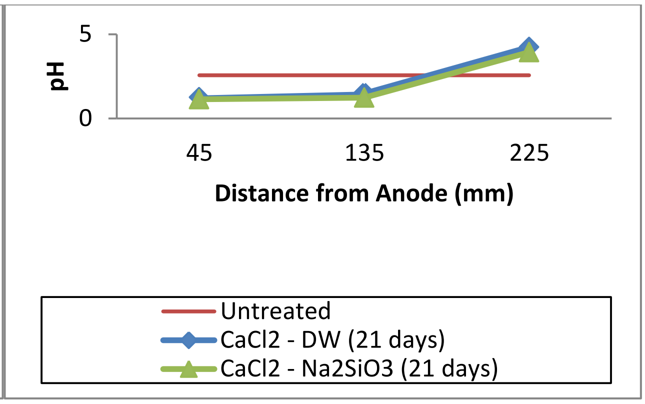

Fig. 6 pH with distance from anode

Since calcium (Ca^+) and sodium (Na^+) ions has been used as the stabilisers towards the soft clay, it is very important to investigate the concentration of those ions after experiment ended. Fig. 7 shows the Ca^+ concentration for both phases and the origin concentration for untreated soft clay was 20.47 mg/l. It shows the concentration increase for both phases and the highest value were occurred at 45 mm from anode. It proves that Ca^+ ions were migrated from anode towards the cathode due to EK process, hence increased the concentration of treated soil in all areas. It have a similar trend with Ahmad Tajudin [8], where the concentration of Ca^+ ion declined at the middle (135 mm from anode) towards the cathode (225 mm from anode) when much longer period was applied. Percolated were occurred during experiment when it shows the concentration decreased towards the cathode and this can be supported by the results of shear strength. Fig. 8 shows the profiles of Na^+ concentration and it shows the concentration increased compared to the untreated clay (1210 mg/l). The increment were much contrast when compared to Ca^+ concentration because Ca^+ ion shows the greatest improvement after experiment ended. The lower increment value of it attributed to the migration of Na^+ ions by EK process and this release being flushed away from the system at the end of cathode chamber.

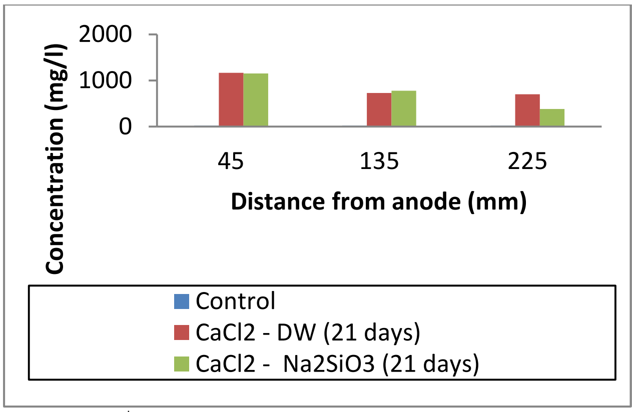

Fig. 7 Ca^+ concentration with distance from anode

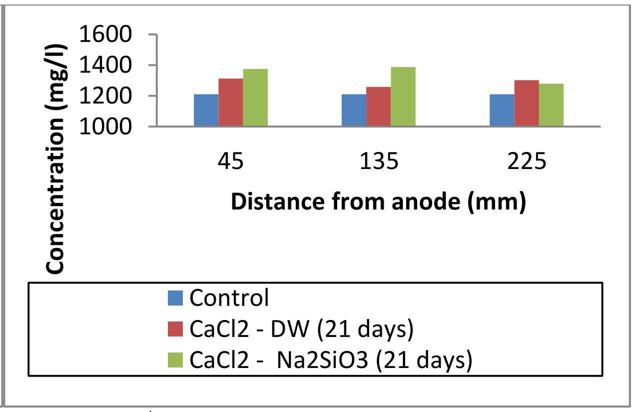

Fig. 8 Na^+ concentration with distance from anode

Table 3 Values of LL, PL, PI, pH and ions concentration

Dist. from anode (mm)	45	135	225
LL, (%) $_{CaCl2\text{-}DW}$	50.14	53.22	62.33

LL, (%) $_{CaCl2-\ Na2SiO3}$	55.88	60.55	68.25
PL, (%) $_{CaCl2-DW}$	35.43	34.34	35.05
PL, (%) $_{CaCl2-\ Na2SiO3}$	36.14	35.05	35.78
PI, (%) $_{CaCl2-DW}$	14.71	18.88	27.25
PI, (%) $_{CaCl2-\ Na2SiO3}$	19.74	25.50	32.47
pH, $_{CaCl2-DW}$	1.25	1.48	4.23
pH, $_{CaCl2-\ Na2SiO3}$	1.14	1.23	3.92
Ca^+ (mg/l) $_{CaCl2-DW}$	1164.00	731.80	703.80
Ca^+ (mg/l) $_{CaCl2-\ Na2SiO3}$	1149.00	779.30	381.30
Na^+ (mg/l) $_{CaCl2-DW}$	1313.00	1259.00	1301.00
Na^+ (mg/l) $_{CaCl2-\ Na2SiO3}$	1375.00	1387.00	1279.00

Conclusion

EKS technique was conducted on soft marine clay at Parit Raja by using $CaCl_2$ and Na_2SiO_3 as the electrolytes and stainless steel plate as electrode. It was running for 21 days and a constant voltage gradient (50 V/m) was applied to the soil. The consumption of $CaCl_2$-DW and CaCl2-Na_2SiO_3 as stabilisers into the soil has significantly increased the strength especially in the vicinity of the cathode for both phases. EKS technique has reduced soil water content due to the electroosmosis process which caused an increase of soil pore water pressure, thus increased the shear strength as well. The addition of those stabilisers also decreased the LL and PL of soft clay. This is due to the high acidic environment after the treatment. The pH values of treated soil shows the soft clay creating an acidic value at the anode and slightly increased to base value towards the cathode. The Ca^+ and Na^+ concentration results make a better understanding regarding to the improvement parameters of soft clay such as strength, LL, PL and pH when those ions were applied to the system as the stabilising agents.

Acknowledgement

The author wish to thank to other members of the EK research group at Research Centre of Soft Soils Malaysia for their help throughout the course of this work, in particular to Dr Saiful Azhar who encouraged to pursue this topic and provided many useful discussions.

References

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

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

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

[4] M.N. Abdurahman, Short term performance evaluation of a rural road embankment with different reinforcement constructred on soft soil pertaining to vertical settlement, Master of civil engineering, KUiTTHO, (2005).

[5] M. Nasim, O. Erwin, C. Gary, A review of electrokinetic treatment technique for improving the engineering characteristic of low permeable problematic soil, Int. J. of GEOMATE, Vol. 2. No. 2. 2011, pp.266-272.

[6] N.S. Nordin, S.A. Ahmad Tajudin, A. Abdul Kadir, Physical properties of treated soft clay by using electrokinetic stabilisation method, Soft Soil Engineering International Conference, (2013).

[7] N.S. Nordin, S.A. Ahmad Tajudin, A. Abdul Kadir, Stabilisation of soft soil using electrokinetic stabilisation method, International Journal of Zero Waste Generation, (2013).

[8] S.A. Ahmad Tajudin, Electrokinetic Stabilisation of Soft Clay, School of Civil Engineering, University of Birmingham, UK, (2012)