Effects of Electro Osmotic Consolidation on South West of Johor: Small Laboratory Scale

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Abstract

Soil clay is one of the problematic soils due to its natural states which have low bearing capacity and high compressibility. The effect and problem of the clay soil characteristic creates a problem for construction especially excessive settlement and this can leads to unstable and potential cracks. At presents, there are few improvement types can be carry out to overcome this problems, and electro osmotic consolidation is one of the options. This method has been applied many years ago especially European country. The study encompasses the determination of water content, Atterberg's limits and undrained shear strength after electro osmotic consolidation treatment of soft clay soils taken from 0.5 m and 1.5 m at south west part of Johor. All the samples were tested accordance to BS1377:1990. An experimental study was implemented in a PVC cylinder tube having dimensions of 300 mm height and 100 mm diameter. In the results of electro osmotic consolidation in copper spring electrodes, the measured undrained shear strength was increased considerably at the anodes especially compared to the initial undrained shear strength due to electro osmosis process and consolidation. As laboratory studies of its measurement have shown, the application of electro osmotic consolidation after the application of a direct current applied voltages of 10 Volts, at the anodes especially: (i) a decrease by approximately 35% in water content; (ii) an increase around 29% in undrained shear strength; and (iii) a decrease about 21% in index plasticity. The results obtained in this study shows that the electro osmotic enhanced 15 kPa vertical loading consolidation is a feasible approach in strengthening of south west soft clay in Johor. It can be clearly suggested that the higher the voltage applied in the system, the higher readings of undrained shear strength and the lower of water content especially at the anodes.

Keywords: soft clay soils, electro osmotic, consolidation, water content, undrained shear strength.

1. Introduction and Literature Review

Since 1940s, the theory of electro osmotic has been used and applied widely, between laboratory studies and in situ. This successful approach was introduced by Reuss in 1809. Since then, experimental studies was carried out extensively, especially to improve the geotechnical properties such as Khairul Nizar and Ismail (2012), Mohamedelhassan (2011), Soo *et al*. (2006), Alshawabkeh *et al*. (2004), Shang *et al*. (2004), Bergado *et al*. (2003), Micic *et al*. (2003b, 2003a, 2002), Hamir *et al*. (2001), Hamir (1997), Shang and Dunlap (1996), Mitchell (1991), Eggestad and Foyn (1983), Lockhart (1983c, 1983b, 1983a), Chappel and Burton (1975), Gray (1970), Bjerrum *et al*. (1967), and Casagrande (1949, 1952).

Typical soft clay soils thickness in Peninsular Malaysia are summarised in Table 1. This table shows that the soft clay soil thickness has a thickness between 3 m to 35 m (Abdullah and Chandra, 1987). Plus, in Figure 2, a typical profile of soft clay in Peninsular Malaysia is shown. Clearly, at the upper layer, the thickness is varies between 5 m and 7 m, and roughly 18 m of soft to very soft marine clay soil is deposited at the below part.

Table 1: Soft clay soils thickness in Peninsular Malaysia (Abdullah and Chandra, 1987)

Locations	Thickness (m)
Perlis – Kedah	5 – 12
Sungai Kedah dam area	8 – 12
Alor Setar airport area	12
Prai area and Pulau Pinang bridge	12 – 25
along the Butterworth – Changkat Jering highways	5 – 15
Sungai Kerian area	10
Bagan Datoh road – Teluk Intan	5 – 11
Port Klang area	8 – 30
Kg. Acheh area – Port Merin	3 – 7
West Johor agricultural development projects area	10 – 35
Kuantan area	3 – 20
Sungai Kuantan bridge area	5 – 12
Port Kuantan area	3 – 15
Chukai area	4 – 8
Semerak – Kemasin area	3 – 10

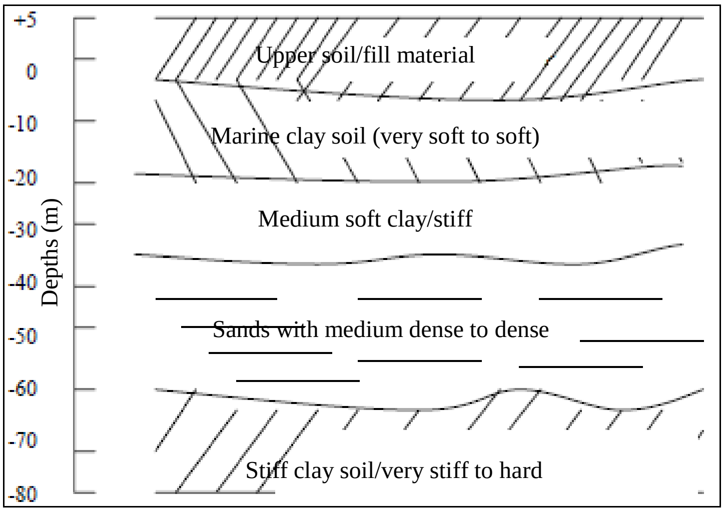

Figure 2: Soft clay soils profile in Peninsular Malaysia (Abdullah and Chandra, 1987)

However, according to Aziz in 1993, the soft clay soils are separated into upper clay soil and lower clay soil (Table 2). He claims that the upper and lower soft clay soil layers took place due to the sea level changes in the Pleistocene era. These changes produced thin sand layers which separated those upper and lower soft clay soils.

Table 3: Upper and Lower Depth Ranges for West Coasts Deposits of Peninsular Malaysia (Aziz, 1993)

Locations	Depth Ranges (m)	
	Upper	Lower
Kuala Perlis, Perlis	0 – 6	6 – 9
Alor Setar, Kedah	0 – 9	9 – 16
Prai, Juru, Pulau Pinang	0 – 12	12 – 22
Bagan Datok, Perak	0 – 11	11 – 22
Sabak Bernam, Selangorr	0 – 10	10 – 23
Port Klang, Selangor	0 – 11	11 – 20
Muar, Johor	0 – 9	9 – 18
Pontian, Johor	0 – 10	10 – 17

In 1985, Lee *et al*. produces a paper with the title of ground improvement works in South East Asia. The authors had noticed that, none of electro osmotic treatment was implemented within these areas. He claims where this technique has not found much popularity, lack of confidence and expertise between researchers and engineers to implement this new technique.

An extensive definitions of electro osmosis was stated clearly by Mitchell in 1991. According to Mitchell (1991:257) states:"when an electrical potential is applied across a wet soil mass, cations are attracted to the negative terminal (the cathode) and anions to the positive terminal (the anode). As the ions migrate they carry their water of hydration and they exert a viscous drag on the water around them. Since there are more cations than anions in soil containing negatively charged clay particles, there is a net water flow toward the cathode".

An extensive series of small scale laboratory studies of electro osmotic consolidation was carried out in a silty clay of south west of Johor at RECESS, UTHM, Parit Raja, Batu Pahat, Johor, Peninsular Malaysia. In that study, 2.5 Volts, 4 Volts and 5 Volts of applied direct current voltages were used (Khairul Nizar and Ismail, 2012). The copper and aluminium plates were used as the electrodes and installed horizontally at the upper and lower parts in the electro osmotic consolidation cell. The results showed that, by applying 5 Volts of applied direct current voltages, the undrained shear strength were roughly up to 24% for aluminium plate and about 28% for copper plate. These results were in general agreement with other past researchers where the undrained shear strength is higher at the anodes and lower at the cathodes. And similarly agreement for the water content, where is lower a the anodes and higher at the cathodes due to electro osmosis (Mohamedelhassan , 2011, Soo *et al*., 2006, Alshawabkeh *et al*., 2004, Shang *et al*., 2004, Bergado *et al*., 2003, Micic *et al*., 2003b, 2003a, 2002, Hamir *et al*., 2001, Hamir , 1997, Shang and Dunlap, 1996, Mitchell, 1991, Eggestad and Foyn, 1983, Lockhart , 1983c, 1983b, 1983a, Chappel and Burton, 1975, Gray, 1970, Bjerrum *et al*., 1967, and Casagrande, 1949, 1952). Table 4 summarises the undergraduate research which completed at FKAAS, UTHM.

Table 4. Final Year Project Students at FKAAS, UTHM under Electro Osmotic Consolidation Studies

Name	Titles
Abdul Kaharudin (2012)	A Comparative Study on the Deformation Effect on UTHM Soft Clay between Electro Osmotic Consolidation and Vertical Sand Drains Consolidation
Habib Musa (2012)	A Study on the Mechanical Properties of UTHM Soft Clay by Applying Low Applied Voltage
Megat Mohd Narawi Hidayat (2011)	Electrocementation of UTHM's Soft Clay Induced by Electro Osmotic
Mohd Imran (2011)	A Study on Improvement of UTHM's Clay via Electro Osmotic Consolidation
Mohd Yusri (2011)	Improvement of the Load Carrying Capacity of UTHM's Soft Clay Soil by Electro Osmotic Consolidation
Wan Khairil Zilikram (2011)	Electro Osmotic Consolidation Cementation of UTHM's Soft Clay Soil

This paper discusses the water content, liquid limits, plastic limits, and undrained shear strength of south west soft clay soils from RECESS, UTHM, Parit Raja, Batu Pahat, Johor, Peninsular Malaysia.

2. Methodology

2.1 Soft Clay Soils at RECESS, UTHM

The south west soft clay soils in this study are taken from RECESS, UTHM, Parit Raja, Batu Pahat, Johor. The undisturbed samples were taken between 0.5 m and 1.5 m depths. All samples were tested on the natural state before the electro osmotic consolidation treatment, and after electro osmotic consolidation treatment. The samples were tested on its water content, liquid limits, plastic limits and undrained shear strength. All the samples were tested accordance to BS1377: 1990 and summarised in Table 5. Table 6 outlines the soft clay soil at RECESS, UTHM.

Table 5: Standard References to BS 1377

Test	Type of test	References	No. of samples	
			Untreated	Treated
Laboratory	water content	BS 1377: 1990: Part 2: Clause 3	5	24
	liquid limit	BS 1377: 1990: Part 2: Clause 4	5	24
	plastic limit	BS 1377: 1990: Part 2: Clause 5	5	24
	undrained shear test	BS 1377: 1990: Part 7: Clause 3	5	24

Table 6: Index Properties at RECESS, UTHM Soft Clay Soils

Index Properties	Khairul Nizar and Ismail (2012)	Researchers (2012)
Water content (%)	59 – 68	74.76
Liquid limit (%)	50 – 60	59.72
Plastic limit (%)	27 – 40	33.37
Index plasticity (%)	16 – 26	26.35
Silts (%)	77	77.45
Clay (%)	23	22.55
Specific gravity	-	2.42
Soil classification	MH	MH

-: no information.

2.2 Electro Osmotic Consolidation Tests

The preparation of samples and the cell dimensions are similar with the techniques which carried out by Khairul Nizar and Ismail (2012). However, four applied DC voltages instead of three (Khairul Nizar and Ismail, 2012) were used in this studies. There are 2 V, 4 V, 6 V and 8 V. The DC voltages were connected between welded cables at the edge and electrodes. The electrodes were made and fabricated into a copper spring electrodes (Figure 3). Between this study and Khairul Nizar and Ismail (2012), the copper was used. This is due to its less corrosion and a good conductor material especially in wet conditions. Filter paper acted as a filter medium so that only water will passed through it when the whole electrodes is inserts into the soil samples in the electro osmotic consolidation cell.

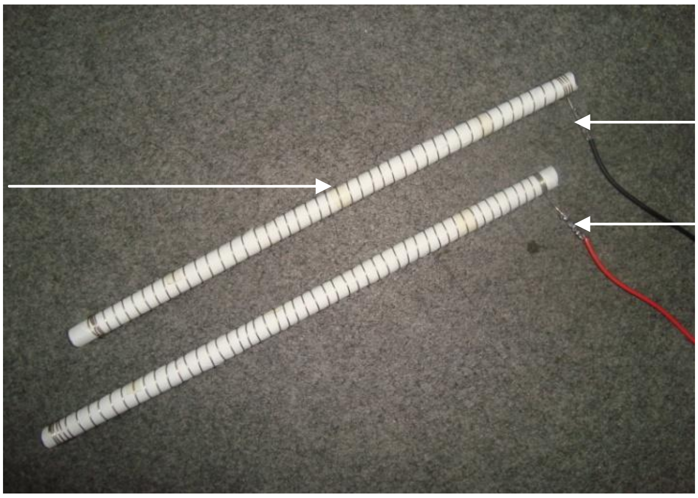

Figure 3: Copper Spring Electrodes

The electrodes were installed in a pentagon shape, as showed in Figure 4. It is known as a five sided polygon, simple or self intersecting with the similar sides is equal in length and each interior angle is 108°. The idea of the electrodes layout was adopted from the studies by Alshawabkeh (2001) and Alshawabkeh *et al*. (1999). The idea of pentagon that was used in the experimental tests is to generate higher effected area between the anodes and the cathode. This idea was an alteration layout from past studies by Alshawabkeh *et al*. (1999) ideas, where in their studies they suggested a hexagonal layout, would produce 71% treatment areas.

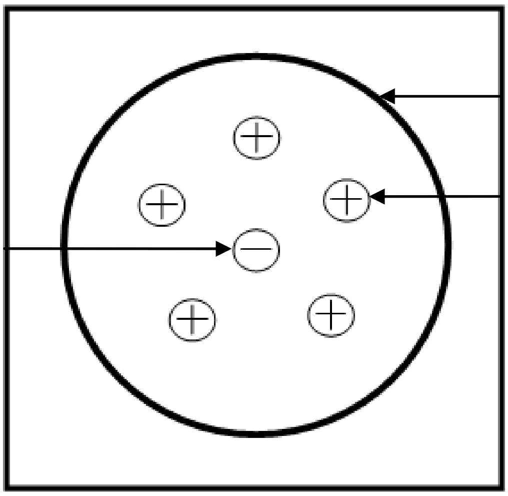

Figure 5: Anode and cathode Layout Pattern

The electro osmotic consolidation cell of PVC pipe tube 5 mm in thickness, has dimensions of 100 mm inner diameter and 300 mm height as shown in Figure 6. The idea of the electro osmotic consolidation cell dimensions was followed according to Hamir *et al*. (2001) and Hamir (1997). The welded cable (Figure 3) connected between the edge of the anodes and the cathodes and dc power supply is monitored via one ampere meter and voltmeter. Five undisturbed soft clay soils samples were used at its natural water content state. The soil was extruding into electro osmotic consolidation cell from a thin walled tube sampler. In each test the electro osmotic consolidation was filled to a height of 250 mm to ensure the 15 mm upper plate and 15 kPa dead loads were fits sufficiently. A filter paper was placed on the top of soil sample under the top plate, and at the bottom of soil sample.

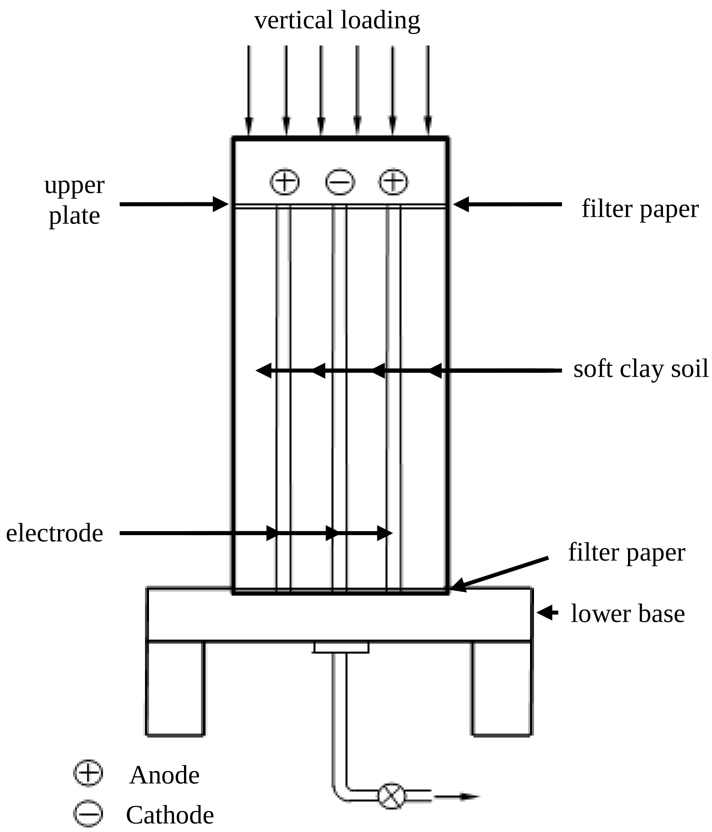

Figure 6: Important parts for electro-osmotic cell apparatus

Upon completion of the setup, a vertical loading of 15 kPa was applied constantly, between phase 1 and phase 2. Roughly, it took 7 days to reach steady state. There were five samples were loaded with the similar loads on the phase 1. However, on phase 2, a constant 2 Volts, 4 Volts, 6 Volts, and 8 Volts were applied during the second phase while still maintaining the 15 kPa external dead loads. This was applied for days to 6 days, depending on the electrode life. The current and dc power supply was switched off when afterwards. The volume of water collected during the experiment, settlement, and current readings were periodically recorded during the testing period. Unfortunately, only water content, liquid limits, plastic limits and undrained shear strength are discussed in this paper.

3. Results and Discussions

One untreated sample and four treated samples for four applied voltages with Atterberg's limits and undrained shear strength test result is presented in Table 7. The water contents of the untreated was about 71% and the water contents reduction attributed to electro osmotic consolidation, therefore, were about 26% (2 Volts), 29% (4 Volts), 33%(6 Volts), and 35% (8 Volts). While representing roughly 21% (8 Volts), 10% (6 Volts), 6% (4 Volts), and 1% (2 Volts) decrease of index plasticity generated by electro osmotic consolidation at the anode. This table shows that the average values at the end of 15 kPa of phase 2 at the anode where water contents, liquid limits, and index plasticity decrease with increasing applied voltages. While plastic limits and undrained shear strength increase with increasing applied voltages. Similar conditions were found in Khairul Nizar and Ismail (2012), Mohamedelhassan (2011), Shang *et al*. (2004), Bergado *et al*. (2003), and Micic *et al*. (2003b, 2003a, 2002). The exchangeable ion, salt concentration and pH of the clay are the main factors that influenced the changes for these characteristics of soil samples (Bergado *et al*., 2003).

At the end of 15 kPa in phase 2, at the end of electro osmotic consolidation, the undrained shear strength of the treated samples were approximately 42 kPa at the anode for 8 Volts, representing about a 29% increase of untreated samples, compared about a 13% increase for 2 Volts. Same agreement were found in Soo *et al*. in 2006 and Bergado *et al*. in 2003 where the increment of undrained shear strength in at the anode section is due to the effect of evaporation of pore water by means temperature increase and pore water flow to cathode.

This phenomenon was attributed to the development of electro osmosis under direct current electric field condition.

Table 7: Laboratory Test Results

Parameters	Untreated	Treated							
		2 Volts		4 Volts		6 Volts		8 Volts	
		Anode	Cathode	Anode	Cathode	Anode	Cathode	Anode	Cathode
w_c (%)	70.76	52.42	76.12	50.03	75.81	47.29	75.07	45.77	74.93
I_p (%)	24.94	24.72	27.96	23.48	26.53	22.57	24.64	19.68	24.05
w_L (%)	57.12	54.14	61.37	52.62	60.42	51.98	58.62	50.37	57.92
w_P (%)	32.18	29.42	34.41	29.14	33.89	29.41	33.98	31.69	33.87
c_u (kPa)	32.57	36.86	27.13	37.31	28.76	39.72	29.85	41.87	30.92

w_c: water content; I_P: index plasticity; w_L: liquid limit; w_P: plastic limits; and c_u: undrained shear strength.

The most significant changes in the undrained shear strength, water contents, and Atterberg's limits occurred at vicinities of both anode and cathode. These are attributed to the strongest electric field at these locations. According to Micic *et al*. in 2002b, this is likely attributed to the electro cementation bonding generated by electro kinetics in a soil samples. The possible causes of this electro cementation could be selective sorption and ionic exchange of ionic species on clay particles surfaces and precipitation of amorphous chemical compound.

4. Conclusions

The soft clay soil at RECESS, UTHM, Parit Raja, Batu Pahat, Johor, Peninsular Malaysia showed a favourable response to electro osmotic consolidation using a copper spring electrodes. The following conclusions can be drawn:

The average values at the end of 15 kPa of phase 2 at the anode shows that the water contents, liquid limits, and index plasticity decrease with increasing applied voltages. While plastic limits and undrained shear strength increase with increasing applied voltages.

The reduction of water content at the anode is roughly 26% to 35% due to electro osmotic consolidation. While, at the anode too, all samples indicated a decrease in index plasticity, liquid limit and plastic limits. The exchangeable ion, salt concentration and pH of the clay are the main factors that influenced the changes for these characteristics of soil samples.

A higher increase in undrained shear strength was obtained after electro osmotic consolidation with 8 Volts compared to 2 Volts. The undrained shear strength of the treated samples representing about a 29% (8 Volts) and 13% (2 Volts) increase of untreated samples.

5. Acknowledgements

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