Experimental study on electro-kinetic consolidation of marine soil

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ABSTRACT

Due to very slow rate of expulsion of water in conventional consolidation technique, different methods have been proposed in time to accelerate the process. Electro-kinetic method is one of the ground improvement techniques which can be used to accelerate the consolidation process and it can be applied without excavation or disturbance of soil in field. The principle of the electro-kinetic treatment involves applying a low direct current (DC) to the arrays of electrodes inserted in low permeable soils that cannot be readily drained. This paper aims to investigate the potential of electro-kinetic treatment to improve the engineering properties of marine soil. The main objective is to study the effect of current and spacing of electrodes on soil properties. Results indicate that as the spacing of electrodes decreases from 45 cm to 15 cm, the flow of current and the quantity of water drained increases. At the end of each test it is observed that both pH value and undrained shear strength is varying at anode and cathode. The rate of settlement per unit volume of electro-kinetic consolidation is observed approximately 2 times more compared to conventional Oedometer test. Also compression index and co-efficient of consolidation increases in comparison to conventional test. In case of electrode spacing of 15 cm, moisture content decreases rapidly.

Keywords: Consolidation, Electro-kinetic, Ground improvement, pH, Undrained shear strength.

1 INTRODUCTION

The soft soils with low bearing capacities suffer from large settlements when loaded and the rate of dissipation of pore water pressure is very low in normal circumstances. The high water content in soft marine clays could loosen the bond between the soil particles, causing high compressibility and low bearing capacity of the soil, leading to excessive settlements of structures. The choice of the appropriate ground improvement technique has to be made depending on the type of soil, the load applied and time available for the improvement process.

The application of an electric field in clayey soils incites electro-osmosis (transport of pore water toward the cathode), Electro-phoresis (transport of negatively charged particles toward the anode), and ionic migration (transport of ions toward electrodes). Electro-kinetics has been used as a soil improvement technique for stabilization of slopes, embankments, and dams (Casagrande 1952, 1983; Bjerrum et al. 1967).

In this paper, an attempt is made to study the influence of spacing of electrodes on properties of marine soil by keeping initial water content and voltage constant. Also, to check the rate of settlement and compressibility characteristics in electro-kinetic test and compare it with the conventional consolidation test.

2 EXPERIMENTAL PROGRAM

Detailed experimental program is described in the following sections.

2.1 Experimental cell

For studying the effect of electro kinetics, the experimental cell was designed with the consideration of the following factors: (1) perforated electrode was used as cathode and solid plate was used as anode; (2) water was drained from the cathode; (3) the current and

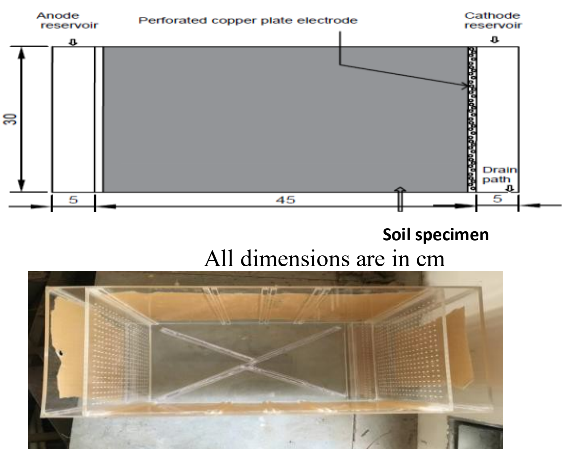

Fig. 1. Schematic sketch of model for Electro-kinetic test and actual model

voltage within the sample was measured during treatment.

The electro-kinetic cell was made up from acrylic sheet of 6 mm thick with an open top. Dimension of model was 55 cm X 30 cm X 30 cm. Two reservoirs, namely anode and cathode were created by providing perforated acrylic sheet partition at 5 cm from both ends in longitudinal direction of model.

Copper plates of size 30 cm x 30 cm and 2 mm thick were used as electrodes. Perforations are provided in cathode plate in order to allow the passage of water. Both electrodes are connected to DC power supply.

2.2 Material

In the present study, marine soil is collected from Dholera region, Gujarat. The index and engineering properties of soil observed from experimental analysis are shown in table 1.

Table 1. Summary of soil properties

Properties	Value	IS Code Referred
Liquid Limit (%)	54	IS 2720(Part 5)-1985
Plastic Limit (%)	26.48	IS 2720(Part 5)-1985
Plasticity Index (%)	27.52	IS 2720(Part 5)-1985
Soil Classification as per IS	CH	IS 1498-1970
Shrinkage Limit (%)	22.59	IS 2720(Part 6)-1978
Specific Gravity	2.71	IS 2720(Part 3)-1980
Free Swell Index (%)	14.28	IS 2720(Part 40)-1977
Optimum Moisture Content (%)	18.4	IS 2720(Part 7)-1980
Maximum Dry Density (kN/m^3)	16.4	IS 2720(Part 7)-1980
pH	8.83	IS 2720(Part 26)-1987
Compressibility Characteristics Compression index(c_c) Co-efficient of volume change (m_v) (m^2/kN) Co-efficient of consolidation (C_v) (m^2/sec)	 0.509 2.379×10^{-3} 1.46×10^{-7}	IS 2720(Part 15)-1986
Hydraulic Permeability (m/sec)	2.98×10^{-9}	IS 2720(Part 17)-1986
Electro-osmotic permeability ($cm^2/s.V$)	4.11×10^{-5} (T1 test) 3.04×10^{-5} (T2 test)	From eq. (1)

2.3 Methodology:

A specific amount of oven-dried soil was mixed with water to achieve a water content of 60% above the liquid limit. The soil was mixed by hand steer for about 30 minutes until a smooth condition was achieved. This mixture was kept in an airtight plastic container for about 24 hours for uniform distribution of water content. The soil was filled up to 22.5 cm in electro-kinetic cell. Then direct current, with the voltage of 10 V was applied by DC supplier to the soil without any application of loading for undertaking the electro-kinetic test. Collect discharged water from cathode during treatment and measured rate of discharge at specific time interval. Test was conducted at 15 cm (EKT1) and 45 cm (EKT2) spacing of electrodes.

2.4 Theoretical background

Electro-kinetic consolidation is one of the techniques that improve the geotechnical properties of the soils. It was pioneered by Casagrande in late 1940s. Casagrande has proposed following equation for electro-osmotic permeability based on Darcy's law.

$$Qe = ke \cdot ie \cdot A = ke \cdot \frac{\Delta V}{\Delta L} \cdot A \qquad (1)$$

Where Q is the quantity of water in cm^3 which moves through an area of A (cm^2) under applied gradient of i_e = V/L (volt/cm) to a soil with electro-osmotic permeability of k_e (m/s)/(V/m).

Here the theory developed by Esrig (1968) is used. He assumed that the physicochemical properties of the soil mass are homogeneous and constant with time, Electrophoresis of fine particles does not occur, the electrically induced flow velocity of water through the soil is proportional to the applied voltage gradient, all applied voltage is useful in producing water transport and the electric field throughout the soil mass is constant with time.

In electro-kinetic consolidation test, the effective stress can be calculated by subtracting pore pressure from the total vertical stress. Total vertical stress can be calculated in the soil by integrating the density between the section and the soil surface and pore pressure can be calculated from boundary condition given by Esrig (1968). Thus the numerical value of the slope of the curve relating effective normal stress (plotted to a logarithmic scale) against void ratio gives the value of compression index (C_c) for electro-kinetic test. Co-efficient of volume change and co-efficient of consolidation is calculated using conventional theoretical solutions.

2.5 Results and discussion

The results of electro-kinetic tests are discussed with respect to (i) current variations, (ii) volume of water drained (iii) increase in the undrained shear strength, (iv) decrease in the soil water content (v) changes in pH values (vi) surface settlement of soil. (vi) settlement per unit volume of soil. These parameters were compared for different spacing of electrode.

2.5.1 Current variations and drained water

The constant voltage of 10 V is applied for the duration of 168 h.

During the initial time period, the current was above 1 A, which is attributed to the high water content and low interface resistance between the soil and electrodes. After certain time period, with decreasing water content and salinity, the pathways of conductance in the soil deteriorated, with a consequent drop in current.

Figure 2 shows that as the spacing between the electrodes is decreased; the flow of the current is more.

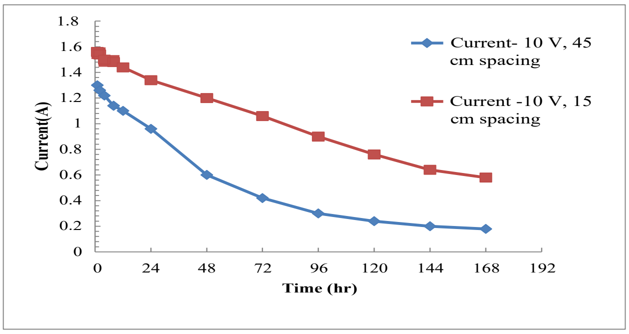

Fig. 2. Change of current with time during EK treatment

The drainage of experiments is shown in figure 3 where the drain water is collected at different time intervals. The amount of water drained is more in test of 15 cm electrode spacing compared to 45 cm spacing.

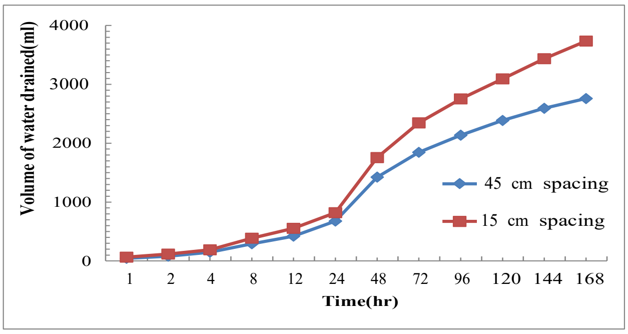

Fig. 3. Volume of water drained from cathode at different time period

2.5.2 Changes in undrained shear strength and water content

The undrained shear strength and water content was measured at three different locations of anode, centre and cathode and at three different depth (top, mid and bottom) at the end of test. The original undrained shear strength was 3.1 kPa.

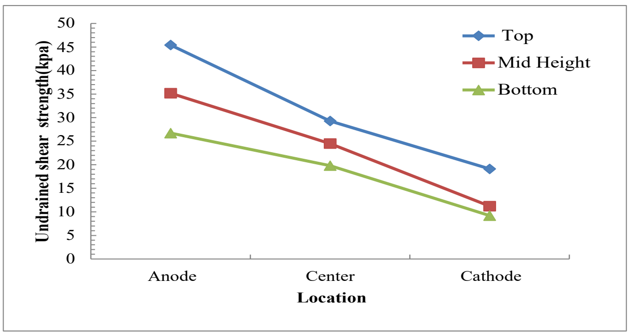

Fig. 4. Profile of Undrained Shear Strength at different location (EKT1- 15 cm spacing)

In electro-kinetic treatment driest region occurs in the vicinity of the anode and the wet part occurs in the vicinity of the cathode due to electro-osmotic flow from anode to cathode.

From figure 4 and figure 5, the soil near the anode has largest strength and also at the top height the strength is more in EKT1 compared to EKT2. The undrained shear strength at top of specimen at anode was found about 45.41 kPa in EKT1.

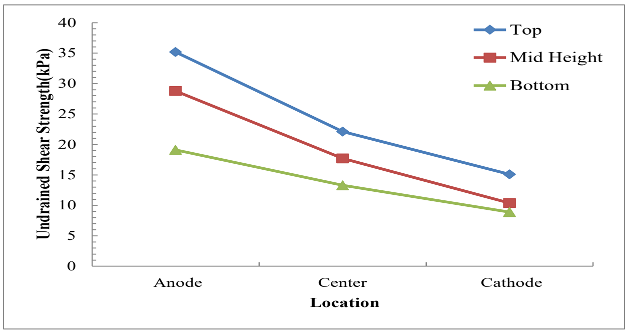

Fig. 5. Profile of Undrained Shear Strength at different location (EKT2- 45 cm spacing)

Changes in the water content profile after treatment is shown in Figure 6 for test EKT1 and in Figure 7 for test EKT2. The initial water content before the test was 86.4%.

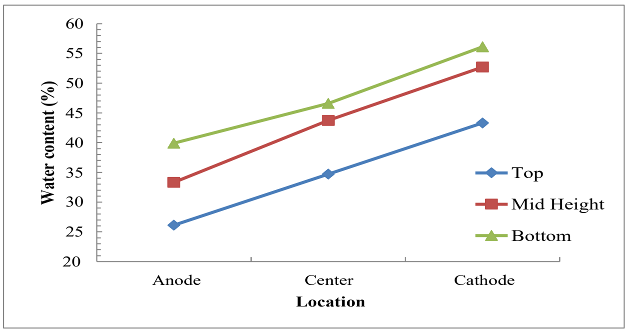

Fig. 6. Profile of water content at different location (EKT1)

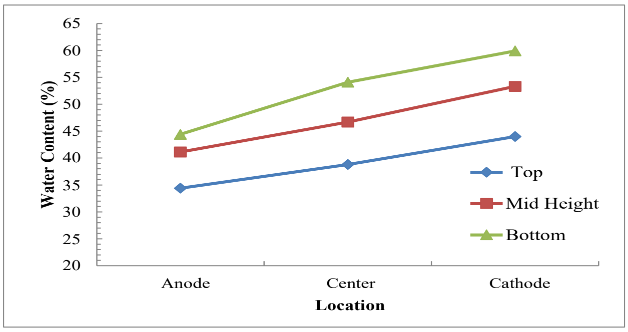

Fig. 7. Profile of water content at different location (EKT2)

The water content after the treatment (EKT1) was found about 26.13% near anode. Draining out of water from anode to cathode side decrease in moisture content in clay which consolidates the clay and thus further improving its shear strength from anode to cathode.

2.5.3 Surface settlement of soil during electro-kinetic test

Surface settlement of the soil during electro-kinetic tests at different time interval was observed from the markings done on sheet of tank and plotted as shown in fig 8. Surface settlement of about 6 cm was observed in test EKT1 while 4.1 cm was observed in EKT2.

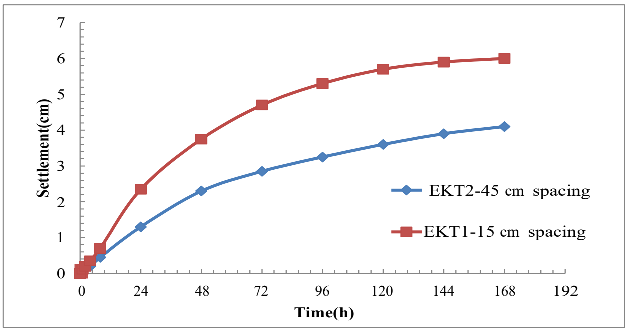

Fig. 8. Surface settlement versus Time during electro-kinetic test.

In case of EKT1 test, the flow of current is more due to less spacing which helps in removing the water at faster rate than test EKT2 which leads to surface settlement of soil at faster rate.

2.5.4 pH changes

The chemical reaction in the cathode and anode cause the creation of oxygen and hydrogen gases and H^+ and OH^- ions. Therefore, the existence of H^+ ions in anode causes the value of pH to decrease and the liquid near anode gets acidic but in the cathode it changes to alkaline. pH of virgin soil is 8.83.

Table 2. pH values at different locations

Location	EKT1	EKT2
Anode	7.14	7.72
Centre	8.79	8.67
Cathode	10.79	10.12

From the table 2, it shows the pH value increases from anode to cathode.

2.5.5 Comparison between conventional oedometer test and electro-kinetic test

Compressibility parameters are calculated from the Esrig's theory and compared with conventional test.

Table 3. Comparison of consolidation parameters of Conventional Oedometer test and Electro-kinetic test.

	Conventional Oedometer test	EKT1	EKT2
Compression index (C_c)	0.509	1.081	0.687
Co-efficient of volume change (m_v) (m^2/kN)	2.379 * 10^{-3}	2.37 * 10^{-4}	5.6 * 10^{-4}
Co-efficient of consolidation (C_v) (m^2/sec)	1.46 * 10^{-7}	1.28 * 10^{-6}	5.33* 10^{-7}
settlement (in cm) per unit volume (in cm^3)	9.62 * 10^{-5}	1.97 * 10^{-4}	1.34* 10^{-4}

The values from table-3 itself suggest that electro-kinetic consolidation is faster than conventional oedometer test.

3 CONCLUSIONS

The following are the conclusion that may be drawn from study,

- As the spacing between electrodes decreases the rate of flow of water increases and substantial improvement in reduction of water content was improved.
- The strength determined using vane shear test apparatus shows increment in strength of soil as the spacing between electrodes decreases. Shear strength in case of EKT1 is about 10.21 kPa more than the EKT2. Also, the undrained shear strength values were more at top as compared to mid and bottom height of specimen.
- The surface settlement of soil was fast in case of lesser spacing.
- pH values decreases near anode while it increases near cathode.
- In order to achieve high strength and low water content values, lesser spacing are preferred.
- The rate of settlement per unit volume of electro-kinetic consolidation was found to be around 2 times more than conventional oedometer test which shows that electro-kinetic test accelerates the rate of consolidation.
- Compression index increased about 2 times compared to conventional test in case of 15 cm spacing and co-efficient of consolidation also increases.

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