Visakhapatnam Chapter

*Proceedings of Indian Geotechnical Conference 2020*
*December 17-19, 2020, Andhra University, Visakhapatnam*

# Enhancement of Soil Stabilization by Electrokinetic Process

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**Abstract.** In this paper, an attempt was made to dewater soft clay using an electro-osmotic process with the inclusion of geotextiles. Two types of electrokinetic cells namely, a cylindrical tank consisting of strip electrodes and a rectangular tank consisting of plate electrodes were used. Experiments were conducted for varying voltages of 60V and 90V and initial moisture content (IMC) of 60% and 70%. The enhancement of soil stabilization is done by placing a geotextile layer vertically between the electrodes. Upon application of current, water is collected at cathode till a steady state is reached. The results indicated that the use of plate electrodes was considered to be more efficient than strip electrodes. The efficiency of dewatering increases with an increase in voltage and further rate of dewatering was improved by the inclusion of geotextile. Hence it is concluded that the type of electrodes, voltage, IMC and the placement of geotextile determines the effectiveness of the electrokinetic process of dewatering.

**Keywords:** Electrokinetic cell, Dewatering, Geotextile.

## 1 Introduction

The increase in demand for land space all over the world due to rapid urbanization has increased the need to construct on soft soil grounds, which were considered unsuitable for construction causing excessive settlement and failure of the structure. To stabilize these soils there are many ground improvement techniques and stabilization techniques. Conventional remediation methods have been known successful in minimizing several damages, however, they are expensive, time-consuming and may be difficult to implement in some existing structures. In this regard, the electrochemical or Electro Kinetic (EK) treatment method can be used as an alternative soil treatment method for remediation of those deficiencies.

Ranjitha and Manjari Blessing [5] have attempted to evaluate the use of Electrokinetic Stabilization (EKS) as an effective method to stabilize soft clayey soil. EKS of soft soil was done by using graphite electrodes as anode and cathode in the first method and similarly a combination of graphite and zinc electrodes as anode and cathode in the second method. The results show that the Liquid Limit was reduced up to 37.27% from 67.45%, Plastic Limit increased from 36.11% to 37.4%, Plasticity Index decreased from 31.34% to 13.73% and Free Swelling Index was decreased to 2.9% from 26%. The results showed that the Graphite – Graphite electrode combination was efficient when compared to Graphite – Zinc electrode combination. Samidurai et al [3] studied the effects of EK treatment at different voltages and at different intervals of time. When the voltage was increased the water collected at the cathode was also increased. The test results indicated that the compressive and the shear strength of the soil has considerably improved after the electrokinetic stabilization treatment of the soil. Hongtao Fu et al [2] conducted laboratory experiments to determine the optimal voltage gradient of electrokinetic consolidation of Wenzhou clay slurry with a small amount of fine sand. The results showed that a steady current was achieved under relatively lower voltage gradients (0.5 V/cm), while higher voltage gradients (1 V/cm) reduced the drainage time. Voltage gradients greater than 1.0 V/cm had no significant effect on the drainage rate.

Wayne et al [4] investigated the effects of high-voltage electric fields on the properties of disturbed marine sediment. The primary experimental data indicated that high-voltage electrokinetics increased the undrained shear strength of marine sediment up to 267% and the pullout resistance of steel plates up to 88%. Geeta and Rakaraddi [1] aimed to evaluate the use of Electrokinetic stabilization as an effective method to strengthen soft clayey soil. After electrokinetic processing, the soil was tested for the shear strength test. Three different anode and cathode electrokinetic systems were employed in this study, under constant voltage of 30V for periods of 3, 7, and 14 days. The chemicals sodium silicate and calcium chloride at different concentrations of 0, 1, 1.5mol/litre were poured at anode and cathode respectively. The combined effect of these processes together with various geochemical reactions alters the chemical composition of the soil porous medium and thereby alters the physico-chemical properties of the soil. The experimental results suggest the potential of developing an electrokinetic treatment technique to stabilize the shear strength of expansive soils effectively and efficiently. Maheshwari and Chandrakanth [6] studied the influence of different arrangement of electrodes on the shear strength of the soil. The various parameters that have varied throughout the test are voltage (20V, 30V), spacing (10cm, 15cm) and different arrangement of electrodes such as 3anode-1cathode (3A-1C), 2anode-2cathode (2A-2C), 1anode-1cathode (1A-1C), 3cathode-1anode (3C-1A).The variation of current and resistance were recorded and the results indicated that the shear strength of soil samples improved considerably after electrokinetic treatment. Before the start of the test, UCC strength was found to be 8.2kN/m$^2$. After electrokinetic treatment, the maximum UCC strength was found out in 3A-1C arrangement (28.64kN/m$^2$). In the case of a 2A-2C arrangement, the UCC strength increases from 8.2kN/m$^2$ to 22.57kN/m$^2$.

In the present study, an attempt is made to carry out the electrokinetic remediation technique to improve and stabilize the soft clay and enhance the rate of dewatering of soft clay using geotextiles placed vertically. Also, the efficiency of dewatering using plate electrodes and strip electrodes is compared for varying voltage and initial moisture content of the soil.

## 2 Materials

Soil sample required for the experimental study was collected from Saidapet (13.0297°N, 80.2380°E) Chennai and tested for its index properties as shown in table 1. Based on the plasticity characteristics, the soil is classified as "CH" type. (Clay of high compressibility or high plasticity).

**Table 1.** Properties of Soil

| Sl.No | Properties | Value |
|---|---|---|
| 1 | Liquid limit, $w_l$ (%) | 60 |
| 2 | Plastic limit, $w_p$ (%) | 30 |
| 3 | Plasticity index, $I_p$ (%) | 30 |
| 4 | Specific gravity, G | 2.71 |
| 5 | Free swell index (%) | 100 |
| 6 | Clay percentage (%) | 71 |
| 7 | Silt percentage (%) | 22 |
| 8 | Gravel percentage (%) | 7 |
| 9 | IS soil classification | CH |

The geotextile adopted is a non-woven type made from high resistance staple fibre polypropylene with needle punching. Needle-punched non-woven geotextiles have far superior flow rates with less tendency to clog than heat-bonded non-woven geotextiles and therefore ideal for drainage and stabilization. It is available in the market. The permeability of the geotextile was found to be 0.005cm/s.

## 3 Methodology

### 3.1 Electrokinetic cell set-up

To study the occurrence of electrokinetic phenomena in soils, an electrokinetic cell is designed and fabricated. The cell includes the components like tank open at the top, electrodes, voltmeter, ammeter and AC to DC transformer. Figure 1and 2 shows the schematic representation of the cylindrical and rectangular electrokinetic cell.

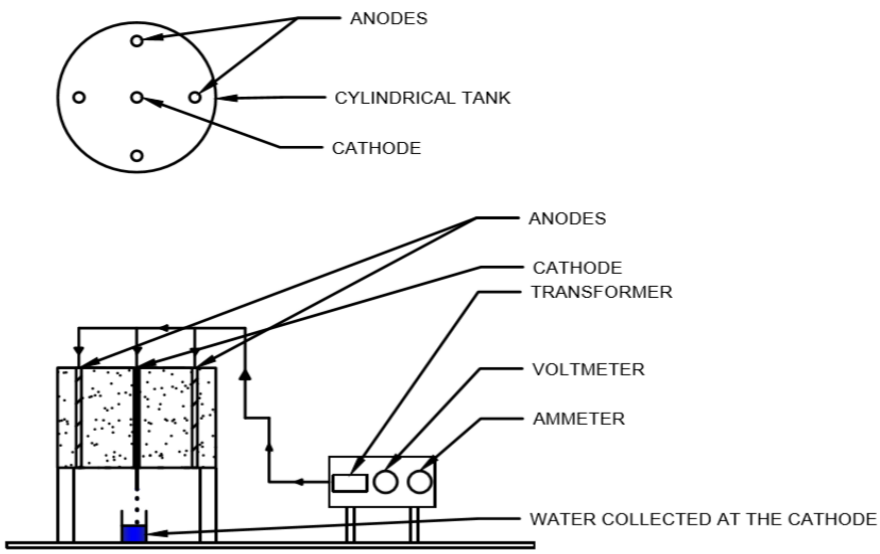


**Fig. 1.** Schematic representation of Cylindrical Electrokinetic Cell (Plan and Sectional view)

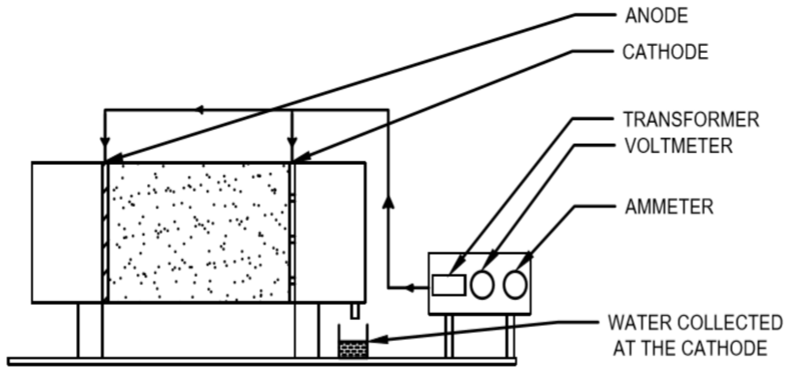


**Fig. 2.** Schematic representation of Rectangular Electrokinetic Cell (Sectional view)

### 3.2 Procedure for dewatering of remoulded clay through Electrokinetic Cell

The following procedure was adopted in the EK cell for dewatering of remoulded clay for varying parameters such as IMC, Voltage and electrode material.

1. To start with, the tanks (namely, rectangular and cylindrical tanks) are filled with equal volume of soil sample by hand remoulding. The electrodes are fitted in the box with the help of the slits provided and the spacing between the electrodes is maintained a constant throughout the study.

2. At the cathode, provision is given to collect water during the process of passage of voltage across the soil sample. The electrodes are connected to the transformer set-up which converts the AC to DC. On applying the required voltage across the electrodes for a specific time, the water is simultaneously collected at the cathode.
3. The volume of water collected is noted at a regular time intervals till the sample reaches a steady-state attaining no more water coming out of sample at the cathodic point. After passing the current, at the end of the test, the soil sample is removed and is tested for its final moisture content and vane shear strength test is performed in the dewatered soil.
4. The experiment is then carried by placing the geotextile vertically in the soil between the anode and cathode penetrating for the entire depth and the electrokinetic dewatering process is performed.
5. The time-cumulative volume of water curves is compared for different voltages, initial moisture content and different material of electrode (Plate electrode and strip electrode). The duration of the test depends upon the time taken for the water collected at the cathode to achieve a steady-state.

## 4 Results and Discussion

The volume of water collected at the cathodic points at a regular time interval until the completion of the tests in EK cell such that there is no more withdrawal of water at the cathode are analysed in the following section for varying voltage and initial moisture content and with the inclusion of geotextile.

### 4.1 Effect of voltage

Voltage is one of the important parameters in the way that it solely decides the time to attain a particular rate of dewatering. Logically one can say that applying higher voltage yields higher dewatering and it is proven in the case of laboratory studies, but upon the application of higher voltage for a longer time, results in the shrinking of soil mass at the interfaces of electrokinetic box. High voltage eventhough increases the rate of dewatering, however crack propagation at early stage is going to hamper the efficiency of dewatering. Especially at 90V, irrespective of the initial moisture content, material and type of electrode, the soil mass shrinks to a greater extent which validates the above discussion. Hence in a real-time application, an optimum voltage has to be applied which achieves a higher rate of dewatering by spending lesser energy.

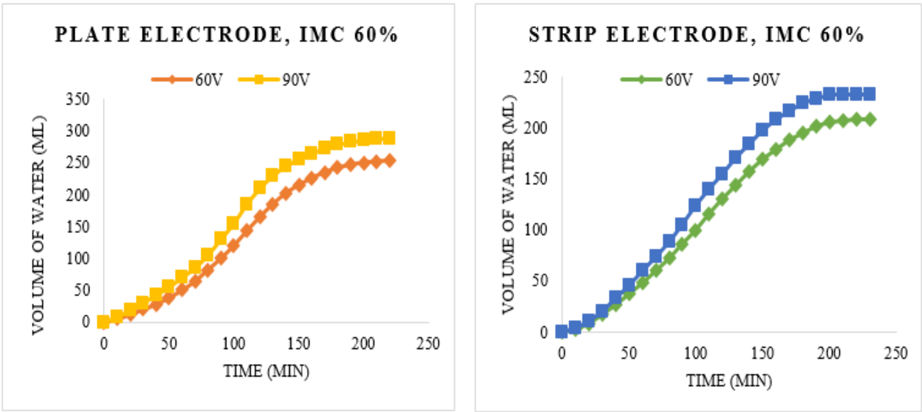


**Fig. 3.** The cumulative volume of water collected at the cathode with time for 60% IMC using plate electrodes and strip electrodes

Figure 3 represents the volume of water collected at the cathode with time for 60V using plate electrodes and strip electrodes. Similarly, graphs are obtained by applying 90V. It can be inferred from the graphs that, for the same IMC, as the voltage increases, the time taken to attain a steady-state decrease. From the comparison between the electrode types, the plate electrode yields more volume of water than the strip electrode for a given volume of soil taken and for a given voltage and IMC.

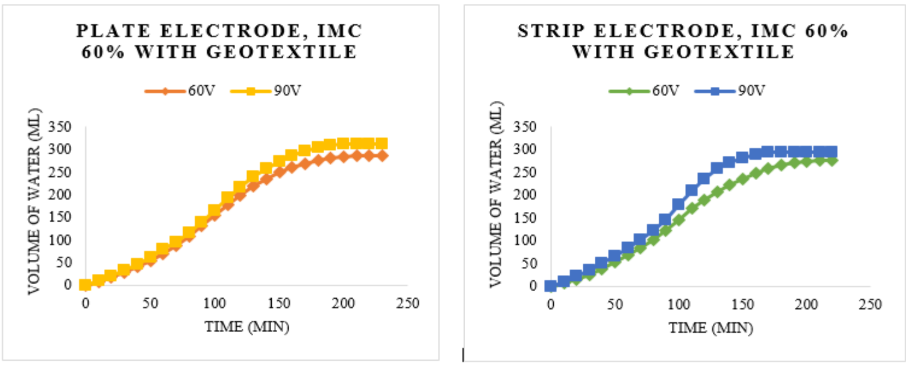


**Fig. 4.** The cumulative volume of water collected at the cathode with time for 60% IMC using plate electrodes and strip electrodes with the inclusion of geotextile.

Similar trends could be found on experiments conducted for voltages of 60V and 90V with the inclusion of geotextile placed vertically in between the anode and cathode conducted for plate electrodes and strip electrodes and the graphs for the above are shown in figure 4. The time taken for the water to attain a steady rate for varying voltage and IMC is shown in table 2.

**Table 2.** Timelapse for achieving a steady volume of water for 60% and 70% IMCs of soil for varying voltage

| Voltage (V) | Type of Electrode | Time taken to attain a steady volume of water at the cathode (min) | | | |
|---|---|---|---|---|---|
| | | 60% IMC | | 70% IMC | |
| | | Virgin Clay | Clay with Geotextile | Virgin Clay | Clay with Geotextile |
| 60V | Plate electrode | 230 | 220 | 300 | 290 |
| | Strip electrode | 220 | 210 | 320 | 280 |
| 90V | Plate electrode | 220 | 210 | 270 | 250 |
| | Strip electrode | 210 | 170 | 310 | 260 |

**Table 3.** Cumulative volume of water collected for 60% and 70% IMCs of soil for varying voltage of 60V and 90V

| Voltage (V) | Type of Electrode | The cumulative volume of water collected (ml) | | | |
|---|---|---|---|---|---|
| | | 60% IMC | | 70% IMC | |
| | | Virgin Clay | Clay with Geotextile | Virgin Clay | Clay with Geotextile |
| 60V | Plate electrode | 253 | 287 | 310 | 338 |
| | Strip electrode | 208 | 275 | 270 | 314 |
| 90V | Plate electrode | 289 | 313 | 330 | 367 |
| | Strip electrode | 233 | 295 | 300 | 341 |

Table 2 shows the increased time taken to achieve constant volume rate of water and table 3 shows the cumulative volume of water collected at the cathode with the increasing voltage and initial moisture content. This can be attributed to the fact that with the increase in IMC of soil, the volume of water available in the soil to be collected at the cathode is also high. It can be observed that as the voltage increases, for the same IMC of soil, the time taken to achieve a steady rate of volume decreases because water drains more quickly at the cathode.

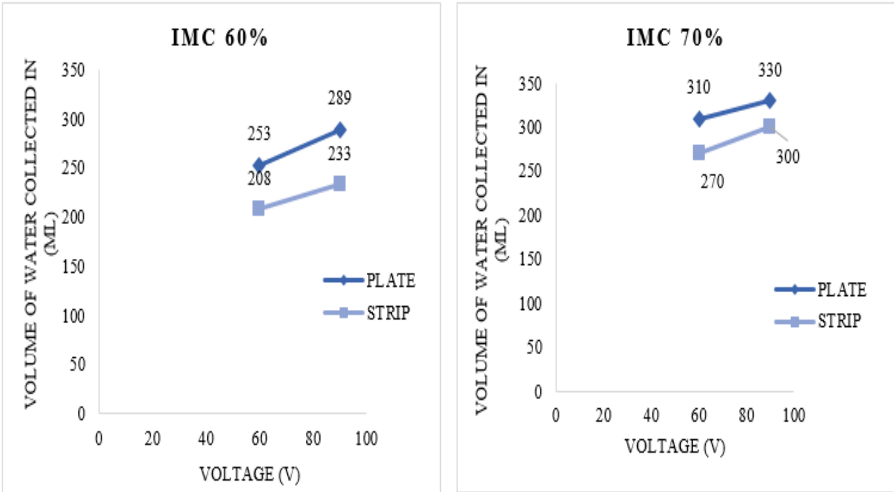


**Fig. 5.** Cumulative volume of water collected at the cathode for IMC of 60% for varying voltage.

From figure 5, it is clear that the cumulative volume of water collected at cathode increases with increase in applied voltage for given initial moisture content. The cumulative volume of water collected upon the application of 90V is found to increase by around 10% more than the volume of water collected on applying 60V. Further, an increase of 8% to 16% of the volume of water was achieved by the inclusion of geotextile on placing vertically between the electrodes.

Table 4 shows the variation in the final moisture content of soil on varying the initial moisture content for varying voltages. The comparison is made for plate electrodes and strip electrodes for varying voltages of 60V and 90V in virgin clay and with the inclusion of geotextile. It can be observed that the final moisture content on applying 90V has dropped more when compared to that of applying 60V and the placement of geotextile vertically between the electrodes has further increased the percentage reduction in water content. This decrease in the FMC of soil is more pronounced for 70% IMC than that of 60% IMC of soil for increasing voltage values. The current cannot flow effectively between the electrodes (through the soil mass) for lower IMCs of soil. This may be the reason why variation in FMC is higher for higher IMC of soil.

**Table 4.** Effect of Voltage, IMC and type of electrode on the FMC

| Voltage (V) | Initial Moisture Content IMC (%) | Description | Final Moisture Content FMC (%) | |
|---|---|---|---|---|
| | | | Plate Electrode | Strip Electrode |
| 60V | 60% | Virgin Clay | 39.2 | 48 |
| | | Clay with Geotextile | 35.1 | 45.5 |
| | 70% | Virgin Clay | 44.2 | 54.2 |
| | | Clay with Geotextile | 39.8 | 50.7 |
| 90V | 60% | Virgin Clay | 36.8 | 46.8 |
| | | Clay with Geotextile | 32.1 | 43.1 |
| | 70% | Virgin Clay | 40.1 | 51.5 |
| | | Clay with Geotextile | 37.7 | 47.1 |

**Table 5.** Percentage reduction in water content

| Voltage (V) | Initial Moisture Content IMC (%) | Description | Reduction in water content (%) | |
|---|---|---|---|---|
| | | | Plate Electrode | Strip Electrode |
| 60V | 60% | Virgin Clay | 34.67 | 20 |
| | | Clay with Geotextile | 41.5 | 24.17 |
| | 70% | Virgin Clay | 36.86 | 22.57 |
| | | Clay with Geotextile | 43.14 | 27.57 |
| 90V | 60% | Virgin Clay | 38.67 | 22 |
| | | Clay with Geotextile | 46.5 | 28.17 |
| | 70% | Virgin Clay | 42.71 | 26.43 |
| | | Clay with Geotextile | 46.14 | 32.71 |

Also, from table 5 it is evident that the percentage reduction in water content is more in the case of the rectangular tank using plate electrodes than cylindrical tank using strip electrodes for a given volume of soil and given initial moisture content with and without the inclusion of geotextile. The percentage reduction in moisture content using plate electrodes ranges from 34.67% to 46.14% and that of strip electrode ranges from 20% to 32.71%. This may be due to the increased surface area of the plate electrodes which are in contact with the soil than compared to the surface area of the strip electrodes. The presence of geotextile further increases the efficiency of dewatering as they possess a higher permeability than soft clay, they form as drainage paths for dewatering to take place at a faster rate and more effectively thereby reducing the moisture content of the soft clay to a greater extent in a shorter duration which results in earlier consolidation of the clay strata.

On the application of a voltage across the soil mass, the soil gets dried up at anode. The portion of the soil that has dried up is removed and the soil sample is subjected to vane shear strength test. Table 6 shows the variation of vane shear strength at the end of the EK test for varying voltage, initial moisture content of the soil and type of electrode. Before the start of the test, the vane shear strength of soil was found to be around 11kPa and 5kPa for initial moisture content of 60% and 70% respectively. After the completion of the test as indicated by the constant cumulative volume of water, the sample was tested for vane shear strength and is tabulated below. A maximum vane shear strength of 14.2kPa and 12.89 kPa was obtained upon the application of 90V in soil containing IMC of 60% using plate electrodes and strip electrodes respectively with the inclusion of geotextile. For soil with 70% IMC, the maximum vane shear strength was found to be 9.6kPa and 8.4kPa using plate electrodes and strip electrodes respectively with the inclusion of geotextile on the application of 90V between the electrodes.

**Table 6.** Vane shear strength of soil with varying voltage

| Voltage (V) | Initial Moisture Content IMC (%) | Description | Vane Shear Strength (kPa) | |
|---|---|---|---|---|
| | | | Plate Electrode | Strip Electrode |
| 60V | 60% | Virgin Clay | 12.5 | 10.51 |
| | | Clay with Geotextile | 13.78 | 11.4 |
| | 70% | Virgin Clay | 7.68 | 6.42 |
| | | Clay with Geotextile | 8.7 | 7.8 |
| 90V | 60% | Virgin Clay | 13.9 | 11.64 |
| | | Clay with Geotextile | 14.2 | 12.89 |
| | 70% | Virgin Clay | 8.82 | 7.52 |
| | | Clay with Geotextile | 9.6 | 8.4 |

### 4.2 Effect of initial moisture content (IMC)

Initial Moisture Content (IMC) is one of the important factors which decides the range of all the other parameters to be involved in the EK based dewatering process. In fact, it is IMC and amount of fine-grained particles responsible for the selection of EK dewatering process instead of the open well dewatering process. Despite the soil's resistance, ions move through the soil by the help of water present in it. Practically IMC level of the site decides the implementation of the entire process of electrokinetics itself. During the testing, it is observed that when IMC is higher, the rate of dewatering achieved is also higher. When IMC is high there is the effective transfer of current and hence, water molecules are easily drawn towards cathodes.

It is usual practice to continue the process of dewatering using electro-osmotic principle only in case of ground with more clay content that too in a slurry state (as indicated by its high IMC even higher than liquid limit consistency of the in-situ soils). Otherwise, the well-point system is sufficient enough to dewater in the case when the soil is having more sand content. In this investigation, an attempt is made to study the soft clay with varying IMCs of 60% and 70%. The IMC of soil decides the voltage to be applied and the time required for the EK process.

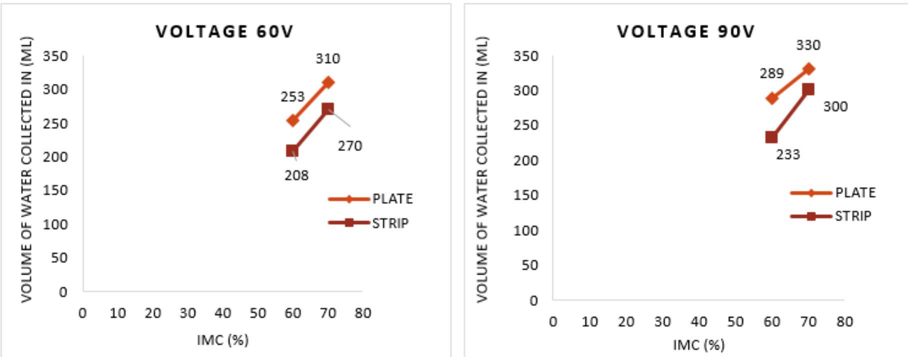


**Fig. 6.** Cumulative volume of water collected at the cathode for Voltage 60V and for varying IMC

Figure 6 below shows that the cumulative volume of water collected at cathode increases with the increase in the initial moisture content of the soil for an applied voltage. Hence soils with IMCs well above the liquid limit are only fairly treated by other dewatering techniques and then this process can be adopted. Now focusing towards the lower range limit of the IMC, at lower IMC, the soil-water discontinuity occurs due to the formation of microcracks at lesser time interval compared to higher IMC of soil resulting in loss of contact with the electrodes. Due to volumetric shrinkage of remoulded clay soil that has been observed in a short span of time at higher voltages soon after the start of passing current also leads to loss of contact between the soil and electrode.

## 5 Conclusions

From the results obtained from the experiments, the effect of voltage and IMC on the properties of soft clay are analyzed and the following conclusions are drawn.

1. As the voltage increases, the volume of water collected at the cathode also increases. The increase on applying 90V is 10% more than on applying 60V. With

the increase in voltage, there is a reduction in FMC of soil and the vane shear strength increases irrespective of the IMC of soil.

2. On the application of current through the soil mass between the electrodes, the soil gets dried up to such an extent that cracks are formed throughout the soil mass which hamper the effectiveness of electro-osmotic process. The cracks developed are a function of voltage applied.
3. The introduction of geotextile increases the rate of dewatering and there is an early attainment of steady state before propagation of cracks. A further increase of 8% to 16% of volume of water was achieved by inclusion of geotextile placed vertically between the electrodes.
4. The use of plate electrodes were considered to be more efficient than strip electrodes. The percentage reduction in moisture content using plate electrodes ranges from 34.67% to 46.14% and that of strip electrode ranges from 20% to 32.71%.
5. As the IMC of the soil increases, the time taken for the volume of water to attain a steady state also increases. This is because of more amount of water present in the soil to get collected at cathode on application of DC.

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