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(Article begins on next page)

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# A review on study of Electrokinetic stabilization of Expansive soil

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**Abstract :** Needless to elaborate the harmful effects of the Expansive soil on the light-weight structures, as it is a very common problem faced by the Structural and Geotechnical engineers all over the world. In INDIA, the site having BlackCotton soil force the local engineers to think differently in order to find a way which can improve the ground condition very efficiently. One solution, which is not used worldwide, is the Electrokinetic Treatment which uses the principle of Electroosmosis, Electromigration and Electrocementation, and has been proved the best for fine grained soil. Till now, inadequate studies have been done to prove its efficiency in using it for the expansive soil. Apparently there may be some reasons why the researchers don't consider this technique useful in such soils. This paper includes the whole and sole of this treatment reckoned from the past studies and its scope in implementation with Expansive soils. Experimental study, both in field and laboratory, followed by its analysis using available software packages, is required to decide the factors of this treatment influencing expansive soil.

***Key Words:*** *Electro kinetic treatment, Expansive soils, Electroosmosis, Electromigration and Electrocementation*.

## 1. Introduction:

Excessive compression, dispersive behavior, collapsing behavior, low shear strength, high swell potential, and frost susceptibility are some of the undesirable properties of soils in geotechnical engineering. Soil properties such as those mentioned would cause severe distress to structures built on them. Needless to say that for trouble-free structures to be constructed on such soils, their undesirable properties must be altered to render these soils as problem-free soils.

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, electrochemical or electrokinetic treatment method can be used as an alternative soil treatment method for remediation of those deficiencies underneath building foundations, roads, railways or pipelines. The use of this technique involves an approach with minimum disturbance to the surface while treating subsurface contaminants and improving the engineering characteristics of subsurface soils.

## 2. Expansive Soil:

Expansive soils are found in many parts of the world, particularly in semiarid regions with alternating wet and dry seasons. The soils in these regions experience periodic swelling and shrinkage during the alternating wet and dry seasons. Such cyclic swell-shrink movements of the ground cause considerable damage to the structures founded on them [Beni Lew (2010)]. In literature, there are a large number of studies done on the geotechnical properties (swelling, permeability and strength parameters, etc.) of the expansive soil, but there is a little data on electrokinetic properties such as Cation exchange capacity, pH and zeta potential of the expansive soil stabilized with some additives. Suat Akbulut and Seracettin Arasan (2010) performed laboratory experiments on Turkish expansive soil to research the variation of cation exchange capacity, pH, and zeta potential in expansive soils treated with additives such as cement, lime, fly ash and silica flume. In addition, they recommended performing more experiments and checking the characteristics of the soil without additive.

## 3. Foundations On Expansive Soil:

Chen (1975) has worked tremendously on expansive soil and suggested various foundations on expansive soil, like Strip footing, Stiffened mat foundation, Chemical stabilization, Moisture control, etc. And others, like Sand cushions (Satyanarayana, 1969), CNS cushion (Katti, 1979), Under-reamed piles (IS 2911 – Part-III, 1980), Granular pile-anchors (Phani Kumar et al., 2004; Hari Krishna P et al.,2013).Mohammad Ali and Shaik Moin Ahmed (2011) conducted experiments on expansive soil to examine the effectiveness of using micropiles as a technique to control upward movement of lightweight structures resting over such expansive soils. The results showed that the percentage reduction in heave due to micropile reinforcement was more for micropiles surrounded by sand in predrilled holes of 25 mm diameter. Similar kinds of studies were done before by Osama K. Nusier et.al (2004).

## 4. Electrokinetic Treatment:

Electrokinetics is defined as the physicochemical transport of charge, action of charged particles, and effects of applied electric potentials on formation and fluid transport in porous media. It is an emerging technique which uses direct current (DC) or a low electric potential difference to an array of electrodes placed in the soil, for removing organic, inorganic and heavy metal particles from low permeable soils, mud, sludge, slurries, sediments and groundwater by electric potential [Nasim Mosava et al. (2012)].

### 4.1. History:

In the past, Electro-osmosis has long been applied in soil engineering. Several patents on the removal of water from clayey and silty soils by electro-osmosis were issued in Germany before World War II. Later, the method was widely and successfully used in Germany, England, the U.S.S.R., Canada, and Mexico in drying water-logged soils for heavy construction. The development of these practical applications has been largely due to the work of L. Casagrande (1930-1962) who noticed that a permanent stabilization of soil could be obtained by using aluminum electrodes, and who has carried on a continuous research on the subject [Lucas Adamson et al.(1966)].

### 4.2. Electrochemical reactions:

Electrophoresis: When a charged particle is suspended in a fluid and electromagnetic energy is applied to the particle, a force on the particle results because of the effect of the field on the charge. This results in the particle moving and dragging some fluid with it.

Electroosmosis: When a surface has considerable charge and is in contact with a fluid, a cloud of opposite charge results in the fluid close to the surface. When an electric field is applied to the volume containing the fluid, the charge in the fluid generates a force that moves the fluid.

Electromigration: It is the gradual movement of the ions or charged electrical species under an electric gradient. The rate of movement and direction of an ionic species is dependent upon its charge, both in magnitude and polarity, plus the magnitude of the electroosmosis induced flow velocity.

Non-ionic species, both inorganic and organic, will also be carried along with the electro-osmosis induced water flow.Figure 1 shows the internal combinations of the complex electrochemical processes taking place during the ELECTROKINETIC treatment, which cause several changes in physicochemical, hydrological and engineering properties of the soils under an electric field. The electroosmotic volume flow rate can be described by

$$\mathbf{Q_e = k_e\, i_e\, A,}$$

Where $Q_e$ is the electroosmotic volume flow (m3/s); $k_e$ is the coefficient of electroosmotic conductivity [m2/(V s)]; $i_e$ is the direct-current electrical field applied (V/m); and A is the total cross-sectional area perpendicular to the direction of flow. The equation is analogous to that of Darcy’s law describing the hydraulic flow driven by a hydraulic gradient. Different theories including: the Helmholtz–Smoluchowski theory, the Schmid theory, the Spiegler friction model, the ion hydration model and the Gray–Mitchell approach have been proposed to quantify the coefficient of electroosmotic conductivity on the basis of different assumptions of ion distribution in the pore fluid [Albert Yeung (2011)].

Previous studies have shown that the application of direct current (DC) during electroosmosis with injection is effective in strengthening soft clay. However, the DC can be obtained from an alternating current supply by use of a current-switching arrangement called a rectifier and a filter. The technique of the full wave rectification may be economically and practically applied in electro-osmotic chemical treatment for soil improvement [Shao-Chi Chien et al. (2011)].

### 4.3. Electrokinetic Treatment on various soils:

Electrokinetic remediation technology has great potential for in-situ remediation of low-permeability and/or heterogeneous soils that have been contaminated by organics, heavy metals, or a combination of these contaminants [Krishna Reddy et al.(2004); Soon-Oh Kim(2004); Sivapullaiah (2007); Krishna Reddy (2010)]. Eltayeb Mohamedelhassan (2011) conducted laboratory Electrokinetic treatments on soft clays to investigate the feasibility of decreasing the water content and increasing the shear strength and axial load capacity. He used fresh water as well as sea water in the experiments and found the former more efficient than the latter. This technique has proved its efficiency in consolidating organic, peat and clayey silt and moreover, Electric Vertical Drains (Geosynthetics) are being used as electrodes because of its huge advantages over the traditional metal electrodes (Figure 3)[Shenbaga R. Kaniraj, et al (2011); Shenbaga R. Kaniraj et al.(2011); Colin.J.F.P.Jones (2011)]. Similarly, Samudra JayasElectrokineticera et al. (2007) conducted experiments on the salt affected soil with the ingress of fresh and lime solution at the anode. There was a dramatic increase in the compresive strength of the soil. However the authors reckoned that electrokinetic techniques would also be an attractive

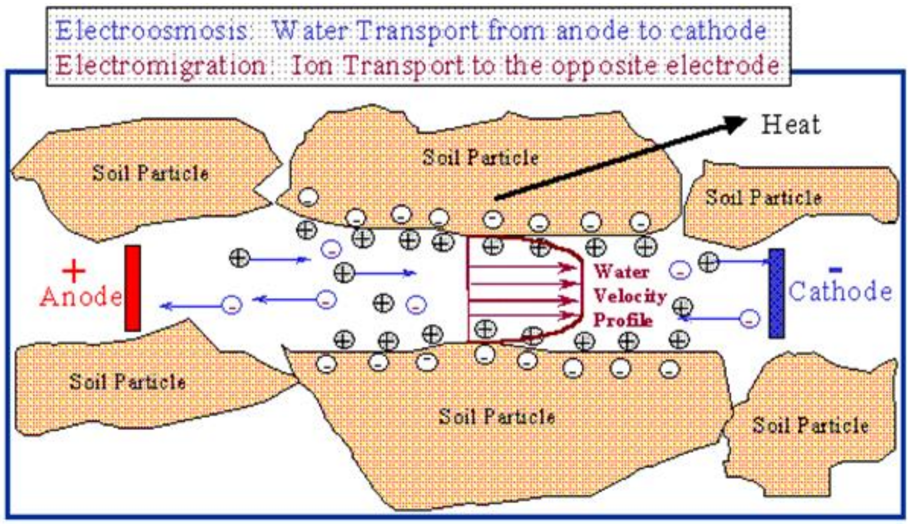


***Figure1:*** *Illustration of electrophorosis, electromigration and electroosmosis phenomenon during electrokinetic process.*

alternative mechanism to introduce lime and or other desirable chemical compounds to the soil, especially

S. Micic et al.(2003) studied the focus on electrokinetic strengthening of soft marine clays adjacent to skirted foundations. It was also evidenced that the soil shear strength was further increased with time after the electric field was withdrawn, attributable to electrokinetics induced soil particle cementation during post-treatment ionic diffusion. Figure 2 a) & b) showed the attribution to electro-cementation of soil particles and bonding between soil solids and steel objects at the soil-steel interface.

***Figure2:*** *Electrocementation near around metal objects. a) Electrodes; b) Cylinder*

Amnart Rittirong et al. (2008) studied the electrokinetic strengthening of caisson anchors embedded in offshore calcareous sand. And also the effects of electrode configuration on the effectiveness of electrokinetic treatment were investigated based on electric field analysis. The electrokinetic treatment generated cementation of soil solids as well as bonding between soil and caisson shafts, which lead to increases in the side resistance and overall pullout resistance.

**4.4. Electrokinetic Treatment on Expansive soils:**

when conventional mixing is not possible for reasons of time constraints, access and depths.

Very few researchers are working on ELECTROKINETIC treatments especially on Expansive Soil, amongst them is as follows:

Samudra Jayasekera (2007) conducted electrokinetic treatment on expansive soil of Australia under different voltage gradients of 0.5, 1.0 and 2.0 V/cm for periods of 3, 5, 7, 10 and 14 days. The test results showed that with electrokinetic treatments, the volume change potentials of the experimental soils reduced to a greater or lesser degree depending on the magnitude of the voltage gradient and processing time. Also, the author, on the basis of experiments, suggested the potential of developing electrokinetic treatment technique to stabilize volume change properties of expansive soils effectively and efficiently.

Abdullah et al.(2009) performed electrokinetic treatment on expansive soil of Jordan (IRBID soil). The authors used chemicals like $Ca(OH)_2$, $CaCl_2$, KOH and KCl for the purpose of extracting Calcium and Potassium Ions, which are efficient stabilizing agents. In the end, they conclude that this technique is an effective technique for delivering, homogeneously, stabilizing agents into soils. However, the potassium ions can greatly improve soil properties due to the linkage provided by the potassium ions as there was a drastic reduction in the values of Plasticity Index and Percent Free Swell.

Nahesson Hotmarama Panjaitan et al., (2012) conducted an electrokinetic treatment with chemicals to find out the phenomenon of Electromigration in expansive soil, in which they found the traces of lime near the anode.

The observations concluded the ability to penetrate the density and plasticity of soil, as well as being able to reach the position of soil to be stabilized at a depth is unlimited. However, they suggest some other tests to be done to determine the influence of the phenomenon of Electromigration, such as atterberg limit test, swelling test and strength of soil test. Laboratory Setups have to be designed as per the requirements and desired output as shown in ***Figure3:***

*Table 1 shows the different sizes of the test tank and various electrodes used for the electrokinetic treatment experiments.*

| **Soil** | **Size of tank (mm) LBH** | **Electrode** | **Drainage** | **Voltage** | **Day** |
|---|---|---|---|---|---|
| Soft soil | 320×125×250 | 14 out dia;10 inner dia perforated with sand | Bottom | 6 & 10 | 7 |
| Organic Soil | 250×110×250 | EVD was cut into 15 mm wide and 240 mm long | Bottom & Vertical geotextile filter | 15-20 V 80 V/m | 7 |
| Marine Clay | 265 ×119×254 | A- 5mm solid steel C- 5 mm perforated Top covered with plastic(short circuit) | Bottom | 6.2 V | 7 |
| Peat & Clayey silt | 250×110×250 | EVD was cut into 15 mm wide and 240 mm long | Bottom | 15-20 V 80 V/m 35V | 6-8 |
| Salt Affected Soil | 900×350×250 | A & C -25mm hollow perforated | Bottom | 35 V | 14 |
| Irbid Expansive | 490×150×160 | Graphite(inert) Active & Passive | Side compartments | 30V | 10 |
| Expansive Soil | 900×350×250 | A & C -25mm hollow perforated | Bottom | 35, 70 V | 3,5,7 ,11,1 4 |

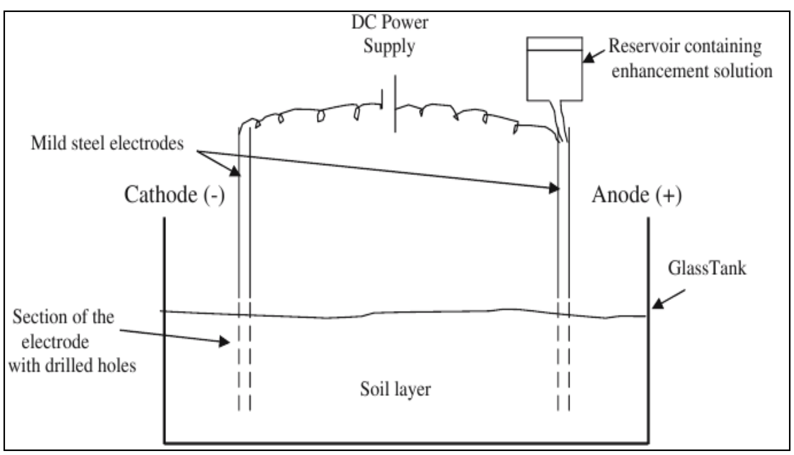


***Figure3:*** *General Laboratory Setup for Electrokinetic treatment*

## 5. Need & Directions For Future Research:

Electrokinetic remediation can be easily integrated with conventional remedial systems to enhance remedial efficiency and decrease the overall cost. There was a distinct improvement in the swelling properties of the expansive soil after the Electrokinetic treatment. As due to Electro-Cementation, formation of ferrous or aluminium oxides in the soil, which are natural cementing agents, 15mm of soil layer was firmly attached to the metal objects (electrodes). So, there is a vast scope if the electrodes are used as anchors, then the phenomenon can be used against the upliftment of the structures by the virtue of friction around the anchors cum electrodes. Following are the significant directions for the future research

- Most of the studies on electrokinetic treatment are focused on contaminated soil and soft clays. A common and solid theoretical understanding for different types of soil still does not exist. More detailed study on effect on the expansive soil should be done. However the effects and degree of improvement of the soil with and without permeating different enhancement (stabilizing) agents through the soil should also be discussed.
- Several changes in soil composition and chemistry, soil physical properties (water content, consistency limits), pH, nature and spacing of the electrodes, processing time, levels of voltage, current and many optimizations need to be further investigated and optimal design concept should be verified through the electrokinetic treatment of the problematic soils.

Experimental study, both in field and laboratory, followed by its analysis using available software packages, is required to decide the factors of this treatment influencing expansive soil. So as to answer the question, "Can Electrokinetic method be considered as a good ground improvement technique for all kinds of soil throughout the world?"

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