



A review on using of both electro-osmosis and electrokinetic soil treatment methods to improve bearing capacity of soft clayey soils

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Abstract

An overview of electro-osmosis (EO) and electrokinetic (EK) soil treatment methods is provided in this paper, along with their impact on pile capacity, installation, and foundation shear strength after improving the geotechnical properties of weak soils, particularly soft clays. As a result of their low shear strength, high compressibility, and poor drainage characteristics, soft clayey soils pose significant challenges in civil engineering. With EO and EK, pore water and ions are moved through the soil matrix under an applied electric field, resulting in consolidation, increased shear strength, and reduced plasticity. This review explores the fundamental principles of EO and EK, including the mechanisms of water transport, ion migration, and electrochemical reactions. It examines various electrode configurations, treatment parameters, and their influence on soil improvement. Furthermore, the paper analyzes the effects of EO treatment on pile capacity, considering both the increase in soil strength and the reduction in pore water pressure during installation. The impact on pile installation methods, such as reducing driving resistance and improving grout penetration, is also discussed. Finally, the review investigates the enhancement of foundation shear strength through improved soil properties achieved by EO/EK treatment. By synthesizing existing research, this paper aims to provide a comprehensive understanding of the potential benefits and limitations of EO and EK methods for ground improvement in soft clayey soils, offering valuable insights for future research and practical applications in geotechnical engineering.

Keywords: *Soft clay, soil improvement, electro-osmosis, electrokinetic, pile installation.*

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1. Introduction

The clay substrata have been disturbed in central and southern flatlands of Iraqi lands. For most sites, the soft to medium clay layer was 5 to 20 m below the natural ground surface.

Numerous methods can be utilized for soft clay improvement for the construction of light or heavy structures upon weak soils (such as the soft to very soft clay layers, for example).

In several soft soil treatment methods, consolidation characteristics are increased or accelerated pre-building loading.

Overall, researches and studies about soft clay improvement have high dissemination level. But our paper is focused on the benefits of the electro-osmosis process applied in soft clayey soil and it would look more closely on the use of the process of electro-osmosis through piling as an application for this method.

The research would clarify recognized studies into three main categories as electro-osmosis soil improvement elements properties studies, using electro-osmosis to improve pile capacity and lastly the

studies which treat the topic of electro-osmosis' effect on the environmental side.

The exploration about using electro-osmosis (E.O.) soil improvement methods led to the main review papers using a wide range of previous studies and these researches considered many parameters which relate to soil properties and the process of electro-osmosis elements.

There were many studies which concerned with soft soils treatment like Zahraa Amad Salem and Asma Thamir Ibraheem's study which deals with sub soil below roads layer engineering properties which it used at waterside street structure and preserve administration program type regulator, During the construction and maintenance process of riverbank roads, quality control is an essential part of ensuring safety, quality, and sustainability of the infrastructure. To avoid potential problems and maintain the road's condition, it is necessary to adhere to technical standards, conduct constant audits, and perform regular maintenance. Subgrade soil is tested for efficiency as the first stage in quality observation. The purpose of

this study is to evaluate the engineering properties of under beneath earth filling layer under river bank roads in order to determine their ability to carry the loads that will be caused by vehicles moving along the road and traffic over the road. To fix soil characteristics and find if the soil requires treatments, soil samples are analyzed and laboratory tests are performed. Al-Kadhimiya Corniche Street was chosen as the location for sampling soils. In this study, the soil was dried out and deals with to research laboratory exams. The soil which tested has a grade of Poor graded Sand (SP). A thickness design based on a subgrade CBR of 26.04% was executed with the use of the software FAARFIELD. In total, 304mm of subgrade pavement were measured. In 2023, an investigation was conducted on Al-Kadhimiya Corniche Street, and the results were confirmed by the actual design that was maintained during the field investigation[2]. Another treatment study was conducted by Sarah R.Salih and Qassun S.Mohammed Shafiq to discuss the consequence of healing fat clay by lime, as a result of extensive soil, civil engineers around the world are faced with significant challenges due to its serious impact on the structures that are constructed on it. The soil exhibits a significant volume change due to a mineral group called montmorillonite. There have been numerous attempts to stabilize soil with chemical additives over the years, with varying degrees of success various additives have been used in soil stabilization, including cement, lime, polymers, and salts. The one that most commonly uses lime is the stabilization of expansive soils, with the aim of improving their mechanical properties. Doing many tests of 3%, 6% and 9% of lime have been added to enhance the engineering properties of Expansive soil. Compaction, sieve analysis, Atterberg limits, hydrometer analysis, California bearing ratio (CBR), consolidation tests, swelling percentages, swelling pressures, and specific gravity measurements were some of the laboratory tests performed.

The mix design was confirmed with test results, results showed that plasticity index, liquid limit, swelling potential, swelling pressure, maximum dry density and specific gravity decreased with the addition of lime (3%, 6% and 9%). In contrast, plastic limit and optimum moisture content was increased. (9% L) lime was strongly enforced to deliver the highest value of California bearing ratio (CBR) changing the CBR 12.13% to 14.65%. (0.070 to 0.030) and (0.581 to 0.193) are the decreases in rebound index and compression index, respectively, due to the addition of (9% L). A reduction of 18.77% to 6.03% of swelling percentage and a reduction of (735.75 kPa to 205.11 kPa) of swelling pressure[3].

Investigating of solid road connecting through edge of concrete block using various axial loads of truck wheels Two researchers What is a rigid pavement system based on research paper rigid pavement system Asma Thamir Ibraheem and Hassan M. Mahdi Rigid pavement system: The rigid pavement systems consist of placing of concrete slabs over the prepared permeable subgrades or foundation layers to provide a long-lasting and continuous surface over the road network. Dowel bars serve as transverse load transfer devices between slab sections, and tie bars provide longitudinal connections. Dowel bar behavior in rigid pavement is influenced by both soil strength and concrete characteristics. Using the Ever FE program, the study was carried out over three key parameters of

interest, viz; The California Bearing Ratio (CBR), compressive strength of concrete and the thickness of the study slab with the application of the different axle configurations on the joint. The negative relationship between the pavement slab thickness and concrete strength is revealed, with constant strength of the soil. Soil strength also increases and the dowel bars see less shear. As the measurement result of this study, soil strength has the dominant role over concrete property on shear load of dowel bars.

The shear load was also significantly affected by the axle type as well as soil strength[4].

Most or all of studies which would be explored were depends soft fine (Clayey soils) due to collect relevant E.O. efficiency.

2. Electro-osmosis process

D.H. Gray collaborated on a major study task involving the electrochemical strengthening of clay soils. Research was conducted to strengthen clay soils by adding aluminum to the soil through an electrochemical gradient. Soil compositional and physical property changes during treatment were carefully assessed, with a focus on treatment pH and pH buffering.

The variations of the strength were divided into three components: the effects of variations of water content and electro-osmotic effect; age hardening and thixotropic effects; electrochemical effects, ion exchange, and mineralization. All treated samples demonstrated electrochemical hardening to some extent.

Solidification was found in bentonitic clays with high water content and high pH. The hydroxy-aluminum which became interlayered in the clay was predominantly associated with this hardening. In contrast, in pH illitic soil with low interlayering, the soil hardening appeared to mainly result from ion exchange.

The presence of aluminum, as well as its distribution in the samples after treatment, was assessed using X-ray diffraction and selective extraction. Catholyte buffering with carbon dioxide accelerated and enhanced aluminum mineralization in bentonitic soils. Post-treatment, the strength of most samples increased in a time-dependent manner—indicating the gradual occurrence of induration independent of reversible thixotropic effects[5].

In comparison to granular soils, clay soils have very low coefficients of hydraulic permeability, so the rate of seepage through clay soils is very low, but drainage can be significantly increased by applying an external electric current to the soil in order to increase hydraulic flow rates.

Clay particles' adsorbed cations and water molecules' Di polarity cause this phenomenon. Fig.1 explains why this happens. In the soil, cations migrate to the cathode when DC electricity is applied.

The pipe is made up of perforated metallic material. Adsorption of water causes it to be dragged along as well. Upon reaching the cathode, the cations release the water and, as a result of the subsequent build-up of pressure, the water drains from the cathode. Upon reaching the cathode, the cations release the water and, as a result of the subsequent build-up of pressure, the water drains from the cathode. Casagrande in Germany in 1939[6].

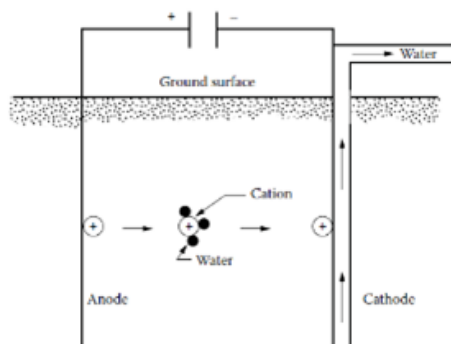


Figure 1. A brief description of electroosmosis principles [1]

3. Electro-osmosis elements effects on engineering weak soils properties

Based on the research of L. Casagrande relating to the electro-osmosis in soils, this paper shows that the movement of water due to the electro-osmotic phenomenon can be supposed to be same value for all types of earth materials. The osmotic permeability (k_e) was recorded as 5×10^{-5} cm/sec, shown in Fig. 2 at a voltage gradient of 1 volt per cm. Associating k_e to hydraulic permeability, the research computed and experimentally ascertained, through laboratory testing, the elevations to which water may be moved through electro-osmosis.

The fact that theoretical balance skulls and test results agree just for a short period of time after inducing an electronic potential in colloidal materials has been attributed to cracks that developed within the mass of material for this purpose. It was attributed.

The acceptancy among the theoretical balance skulls and the test grades with colloidal supplies usually takes location only for just a little time period right away after implementation of the electric prospective, and that is caused by the look of cracks inside a kind of substantial.

The possibility of moving pore-water from cut is discussed and illustrated by the research. For some configurations of electrodes estimates are given of the order of magnitude of the energy dissipation needed.

It also gives an explanation of the preferential consolidation of the soft soil deposits.[7].

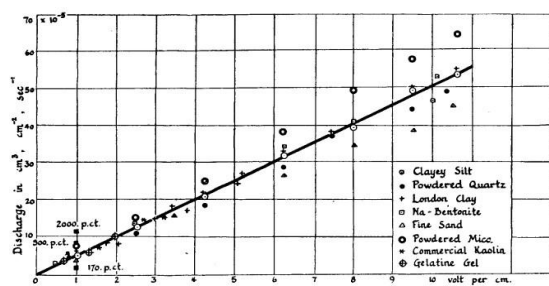


Figure 2. discharge of water by electro-osmosis [6]

Fabien Burnotte et.al., were discussing a case record of E.O. consolidation of soft clayey soil which enhanced at or near-earth fill probe interaction.

Although it has been understood for many years in geotechnical engineering, E.O. consolidation of clays is very rarely employed.

Power losses at the soil–electrode interface is a significant issue for the field deployment of E.O. consolidation, according to a review of published data from case records. The effectiveness of a chemical treatment at the electrodes to improve potential transmission to soil has been shown in a lab study that replicated field circumstances. In a sizable field demonstration test, more than 700 m³ of clay were electro osmotically consolidated to assess the chemical treatment. The site, field setup, monitoring findings, and analysis during the 48-day E.O. therapy is all described in the study. Additionally presented and discussed are the findings of the post-treatment geotechnical investigation following 12% clay compression brought on by electroosmotic consolidation[8].

Sahib, Amal Azad and Vinod, P. conducted study on the assessment of diverse probe patterns in E.O., Electro-Osmosis technology is an established stabilizing method for fine-grained soils. When an electric field is given to a soil mass, the pore fluid migrates from the anode to the cathode, accompanied by positive ions moving toward the negative electrode; the overall effect is diminished water content and enhanced strength in the vicinity. An initial investigation determined that copper and its alloys constitute the optimal electrode material for electro-osmosis, and that a consistent rise in soil resistance during the process enhances its effectiveness. The deployment of this technology in the field typically does not adhere to a specific electrode design. This study adopted various electrode arrangements of four electrodes to examine the impacts of each configuration. A tetrahedral arrangement with one central anode and three cathodes achieved a 33% enhancement in water drainage, while a configuration with one central cathode and three anodes yielded a 76% gain in strength[9].

A.R. Estabragh et al. described the effectiveness of EO on the modification of-clay soil based on laboratory investigation, determination the treated soil vertical movement, chemical and physical of treated soils behavior, Electrical method (e.g., EOT) has a reduction effect of electro-osmosis permeability coefficient of the treated soil (gradually reduce with current increased), while it has raised PH that was reacted in anode and cathodes reservoirs, from the overall results, liquid limit and plastic limit reduction leads to liquid limit index increase, which increasing soil shear strength [10]. Jian Zhou et.al. used E.O. for reinforcing of silts depending on the probe's type, Electro-osmosis is considered a prospective technique for attractive silts, which is a major challenge for engineers because an immense quantity of silts is produced each year requiring safe disposal. Electrode material is one of the most critical factors of the electro-osmosis technique. However, there is existing literature with conflicting results regarding the performance of common electrode materials. In order to understand these disparities and find out the ideal electrode material used for the function, four common materials, including iron, graphite, copper and aluminum were experimented to verify at 3 levels of voltage gradient under laboratory conditions. Two physical phenomena were considered in our observations: the electro-osmotic effect and ionic strength [11]. Zhijia Xue et al. research the effect of electrical energy and temperature on electro-osmosis experiments subjected on naval clay, the study depends many of laboratory tests, through the study the author observed that using electro-osmosis would raise soil

temperature then it will decrease moisture content so the shear strength recognized to improve, also the altering more parameter like voltage was conducted which it recorded that increasing in its value caused more anode corrosion but more shear strength increment and moisture losses furthermore many parameters taken into consideration like degree of consolidation and soil resistivity therefore; it clear to refers that using electro-osmosis would decreased electric resistivity of clay prototype and accelerating consolidation process as Fig.3 reveal[12].

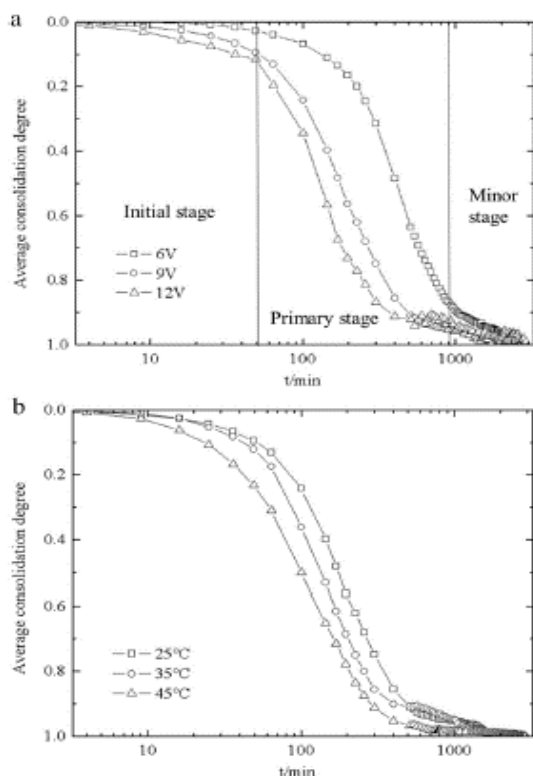


Figure 3. Midding consolidation grade difference versus (a) the voltage (b) the temperature imposed through E.O. testing.

H. Fu et al. investigated the potential of the combination of vacuum preloading and variable-spacing electro-osmosis (EO) for soft ground improvement through laboratory experiments. Tests of dredged marine clay slurry, which is commonly used for tideland reclamation, were performed twice as representative tests. Vacuum preloading alone was used in the first test, and the second one combined vacuum preloading with variable-spacing electro-osmosis. The combined approach was actually composed of three periods: vacuum preloading only, vacuum preloading plus large-spacing EO, and vacuum preloading plus small-spacing EO[13]. Yimin Liu et al. looked back at the history of E.O. Stabilization on Soft Soil: Experimental Studies and Systematic Models, electrokinetic stabilization is a novel technology, pioneered by Cassagrand in 1940, utilized for the stability of railway embankments. In comparison to traditional foundation treatment methods, electrokinetic stabilization demonstrates superior efficacy and reduced duration on soft clay foundations characterized by a fine grain particle and a low hydraulic coefficient. Nonetheless, E.O. has not been extensively implemented in applied engineering, particularly in large-scale applications, owing to insufficient

comprehension of the E.O. treatment mechanism and the discrepancies between theoretical predictions and actual outcomes, in this paper, we will give a short historical overview of the development of electrokinetic stabilization in soft soils. These include studies on the fundamental mechanisms, laboratory and field assessments of key factors affecting E.O.[14].

Lucas Martin et al. explored the E.O. treatment method and its effect on pumping water from soft clay, fine soils, sediments, and sludge SSS management, the electro-osmotic productivity of treatment is dependent on the electrical resistance of the scheme. As SSS resistance builds with treatment, the process becomes less cost effective, and thus limits the use of this technique. This article will discuss the key motivations behind the increased SSS resistance during treatment and will highlight the most updated and commonly applied alterations on conventional electro-osmotic approaches, which will help to alleviate those issues and to amend the efficacy of this technique. These approaches involve polarity reversal, periodic alternating current, emplacement of chemical solutes at the electrodes, and employment of geosynthetics[15].

A potential experimental assessment of the influence of electroosmosis therapy on the chemical and mechanical properties of expansive soils is being considered by Mohammad Khalil Kherad et al., Expansive soils exhibit significant sensitivity to moisture, resulting in a complete alteration of their properties upon the absorption and desorption of water[16].

Wenhao Jiang et al. conducted a mathematical solution study on large strain consolidation of a massive consolidated weak clayey sample under E.O. and pressures, The assumptions of one-dimensional giant strain consolidation are made. The present study concerned with the consolidation of soft soils under the combined preloading by means of E.O. and load quartet. In this article for the first time the exact general analytical solution is achieved in the framework of the algebraic transformation and the method of separation of variables.

The degree of small-strain and large-strain settlements will decrease with an increase in coefficient of volume compressibility (m_v) [2]. The theoretical difference between the two consolidations types also increase for larger m_v . The derived analytical solution is simple and general, which can be used to analyze one-dimensional large-strain consolidation behaviors under electro-osmotic effects and surcharge preloading[17].

There was an experimental trail to observe the vertical displacement for gypsum soils by electric technique conducted by Methaq A. Talib and Qasim A. Aljanabi; An electrical field is applied among the positive probe and the negative one to facilitate electro-osmosis. During this study, a soil sample with ($L*W*D$)(30 x 30 x 25) cm, and a wooden box with (30 x 30 x 30) cm was prepared. To confine the water, the box was placed in a water tank measuring (50 x 50 x 35) cm. A wooden box is filled with two types of gypsum soil that contain gypsum (30% and 60%). For a rigid foundation simulation, a rectangular plate with a thickness of 3 mm was used, and time-leveling tests were carried out for (10) volts, along with orientation records (lacking any electrical energy applied for judgement) when the pressure was changed (20 and 28) T/m². The variables in this study are the gypsum content, the time, the applied load, and the

corresponding settlement. In the results, the soil responded to E.O., but there is a noticeable improvement in settlement Figure (4)[18].

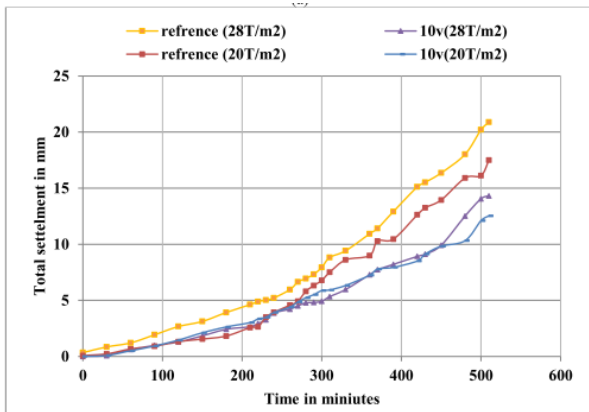


Figure 4. Time-settlement relationship for soil 2[17]

Contributed the interface resistance in E.O. to K.-S. Guo and Y.-F. Zhuang by a means of measurement. Electro-osmotic consolidation is a widely-used technique in dewatering and consolidation for soft ground. Electrokinetic geosynthetics (EKG) electrodes were employed to determine if the interfacial resistance between an electrode and soil is current dependent for initial stages of electro-osmosis. The experiments not only confirm the potential gradient with the efficiency of E.O. but also provide a theoretical basis for determination, optimization of the electric power in the E.O. process [19].

Ansam Mukhaiber Wahhab modeled the soft clay in two methods: The first method is the use of granular materials in the form of drilled columns. The numerical model is established based on the Finite Element Method (FEM) to study the settlement behavior of the granular column-improved soft soil in this study. The last soil model was made according the L 6m-D 8m. Weak soil is treated with granular columns of different depths (4, 6, and 8 meters) and diameters (0.5, 0.8, and 1 meters). Settlement behavior is tracked over the course of 180 days. To further reduce surface settlement and excess pore water pressure in treated soft soil under the electric field, the contribution of electric model behavior under low, medium, and high voltages (5, 15, and 30 volts, respectively) as a secondary impact mechanism of residual electric current on surface settlement and pore water pressure mechanism was explored of granular columns in soft soil.[20].

For soil containing granular columns at an increased load of 72 kN/m², the improvement percentage reaches 50%. That percentage jumps to 87% when 15–30-volt electric current is passed through. Under this load, PWP increases further than it did under previous loads, in an effort to counter the applied stress (it reaches its maximum value before water is expelled, and thus PWP decreases with further consolidation until it reaches zero). The magnitude of enhancement for earth preserved with coarse gravel columns is 60% due to the applied stress of 108 kN/m², while the application of 15–30 volts of electric current showed improvement of 92%.

After the study summarizing results Fig.5 could be useful to indicate the effect of using coarse bar and E.O. through soft clayey soils, relation curve gave that settlement records more than in coarse column[20].

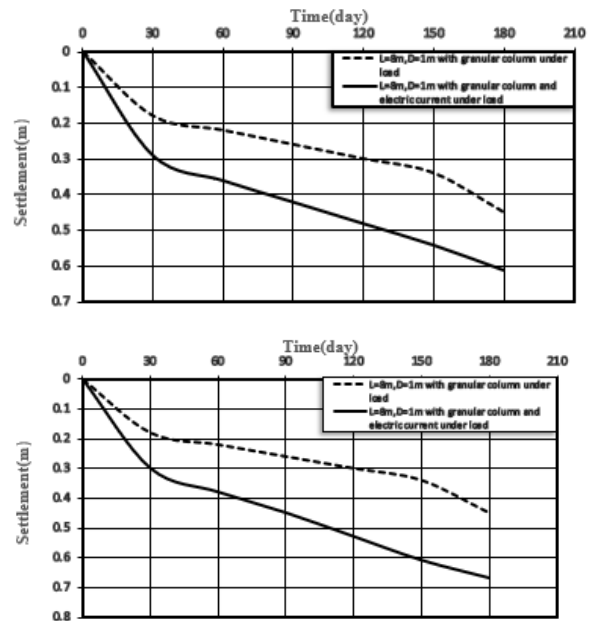


Figure 5. Relationship between settlement and time of soft soil treated by granular column and electric field [19]

Ali zareh et.al., try with the effectiveness of the E.O. procedure which induced through consolidation and clayey soil shear strength characteristics located at Tabriz area. The study investigates impact of electrode type and also discusses how the input electric field responsible for settling the sample, three electrode types (Iron, Copper, and Aluminum) were employed, as well as twice electrical energy (12V and 24V). E.O. is more effective than (standard kaolin Clay) KC when applied to gray clay in Tabriz, where grey clay tends to settle more when exposed to an electric field compared to gray clay in KC. There is also a discussion of the influence of the EO method on the sample strength when it is applied to unconfined compression tests of some samples. Results obtained specify that the EO method can be effectively applied to the gray clay of Tabriz to improve its consolidation and strength properties [21].

P. Wang et.al., try with the observing using of several biopolymers in electroosmotic consolidation of soil, Flocculation E.O. consolidation is a prevalent technique for soil remediation. Nevertheless, conventional inorganic flocculants may accumulate in the soil, rendering it poisonous. In this study, multiple types of biopolymers, having flocculating and biodegradable features, were employed for improving the electro-osmotic consolidation of soil, thus seeking feasible substitutes for inorganic flocculants. Various model experiments were carried out on re-molded soil samples treated with biopolymers including guar gum, chitosan, xanthan gum, sodium carboxymethyl cellulose, locust bean gum and sodium alginate. After the experiment, parameters such as the volume of discharged water, drainage rate, current, soil resistance, electrode potential loss, cumulative energy consumption, water content and bearing capacity were analyzed for soils treated by the same biopolymers [22].

Liming Hu et al. made study on Experimental Investigation of Soft Soil Enhancement via deep electro-osmotic consolidation method, E.O. consolidation has been extensively researched as a method for

enhancing soft soil. Based on this study, it is recommended that electro-osmotic consolidation be performed at a certain depth where the efficiency of drainage and consolidation improve[23].

Zheng Ruoxuan et al. proposed a large-scale 3D electro-osmosis-hydraulic synergism system for sludge consolidation and energy efficiency, and the relationship between sludge properties and energy consumption was analyzed. Therefore, this new method of 3D electro-osmosis-hydraulic synergistic consolidation is investigated based on electro-osmosis and consolidation mechanisms to overcome the problems of high energy consumption and the imitative difficulties of real condition applied to low-permeability, high-water-content soils. The multi-functional drainage system of the catchment was proposed using the synergistic effect of the cathode-catchment-intermittent pumping mode. The consolidation of two types of Taihu Lake sediment, those from the Gonghuwan wetland and Baimao Storage site was studied using the system[24].

4. Electro kinetic treatment on soft clay soils

Guy Lefebvre and Fabien Burnotte, Enhancements of E.O. consolidation of weak clays by diminishing energy loss at probes, even though electroosmotic consolidation of soft clays has shown promise in many laboratory studies, However, electroosmotic consolidation of soft clays is seldom applied in practical settings, despite looking promising in laboratory research. It is difficult to transmit electrical potential through electrodes to the soil deposit, according to well-documented case records of field applications. When the soil is in contact with the electrode, a significant amount of electrical potential is lost. In spite of its promising results in laboratory studies, electroosmotic consolidation has rarely been applied in practical situations. The use of electrodes to transmit electrical potential to soil deposits has proven to be difficult in a well-documented case record of field applications. It is indeed true that a substantial amount of electrical potential is lost in the soil–electrode contact area. Using a laboratory setup that mimics the conditions occurring during electroosmotic consolidation, the loss of potential at this point has been examined. According to laboratory results, approximately one third of the electrical potential applied at the electrodes is transmitted to the soil and is available for electroosmotic consolidation. A chemical treatment designed to increase soil conductivity at the soil-electrode contact has been shown to substantially improve electroosmotic consolidation performance by doubling the electrical potential transmitted to the soil[25].

The above researcher was carrying out investigation on electrokinetic in soils using study of electrokinetic processing impacts on the parameters of salty soil, as a part of study of effects of electrokinetic treatments on some chemical and physical properties of salt contaminated soils present experimental results; further, LL and PL dropped in anode and increased in cathode [26]. Samudra Jayasekera and Steve Hall, consider the effect of electrokinetic to change engineering properties of lean clayey layer with respect to lab experimental data, through this project, an electrokinetic in-situ soil dealing procedure was verified by means of research laboratory tests models in order to determine whether the

technique could be used to improve the engineering properties of soft and low permeable clayey soils, with or without stabilizing agents. A variety of engineering properties were measured after electrokinetic processing of soil specimens, like compression strength, consistency limits, linear shrinkage, and free swell index. According to the results, soil compressive strength and workability increased considerably as a result of the reduction in plasticity index[27].

Rittirong et al. be studied the electrokinetically improvement of soft or weak clay by using electro-dynamically vertical drains. Both laboratory testing and a field experiment were used to assess the efficacy of electrical vertical drains (EVDs). In laboratory investigations, the electrokinetic conditioning raised the undrained shear resistance of a London, Ontario natural clay soil from 3 kPa to greater than 100 kPa. In a field campaign with marine clay, the undrained shear strength of the soil increased from initial values of 5 kPa–13 kPa to an average of 22 kPa–39 kPa after 5 days of electrokinesis with EVDs. Electro-osmotic water flow stopped instantly as soon as electric current was actuated, according to both laboratory and field tests. It was concluded that the soil cohesion and angle of internal friction were increased, attributed to a decrease in water content and an increase in Atterberg limits, developing through an electrochemical process[28].

Soft clay strength stabilization with the use of electrokinetic treatment method was also examined by E. Mohamed Elhassan. The other study mentioned involved the modification of soft clay soil in the laboratory using a specific method to achieve reduced water content, increased shear strength, increased preconsolidation pressure, and increased axial load capacity. Experimental tests for water contents, shear strength, and preconsolidation pressure were performed in four identical electrokinetic cells with a volume of 10 liters each. During these tests, a DC of 10 V was applied with 54 W of energy consumption per test. A 5 V DC voltage was used for the axial load capacity study.

Because the electrokinetic treatment forced water to move toward the cathode, moisture levels became lower over the entire cell, with the lowest values near the anode (32.8% compared with 52.7% in the control). Undrained shear strength also increased in the cell, with the greatest strength observed closest to the anode (62.5 ± 6.2 kPa vs 6.3 ± 2.1 kPa in the control) Fig.6.[29].

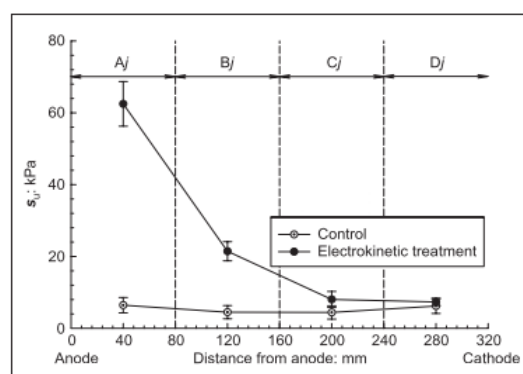


Figure 6. s_u , plotted against distance from the anode after EK treatment: test 1[29]

Jones, Colin J.F.P, Applications of Electrokinetic Geosynthetics (EKG) in Hydraulic Studies. By nature, most of the geosynthetics play a passive role. However, in addition to the standard functions performed by geosynthetics, new applications with geosynthetics capable of inducing biological, chemical, or physical changes in the nearby matrix have been developed. Electrosynthesis makes use of the electrokinetic phenomena of electro-osmosis or electrophoresis and other related processes such as electrolysis, integrated with the conventional functions of geosynthetics, namely drainage, filtration, containment and reinforcement[30].

Colin J. F. P. Jones et al. write research about ecological sustainability of electrokinetic geosynthetic-reinforced slopes, Failures of cut and embankment slopes are prevalent and anticipated to rise. Traditional restoration methods encompass purchasing supplementary land, decreasing the slope angle, implementing drainage enhancements, soil nailing, and/or giving structural reinforcement. New stabilization methods that are more efficient and cost-effective than conventional techniques are emerging, one of which is the electrokinetic geosynthetic treatment for deteriorating or collapsed slopes. The advantages of electrokinetic geosynthetic treatment regarding engineering sustainability encompass decreased costs, diminished carbon dioxide emissions, fewer heavy goods vehicle trips, elimination of waste removal, minimal material importation, reduced noise and vibrations, enhanced air quality, preservation of the seed bank and soil ecosystem, minimal vegetation clearance with the retention of nearly all trees, absence of visual impacts, no disruption to passing motorists, and reduced damage to root protection zones[31].

Through laboratory-based investigation, S. Jayasekera started a discussion on the use of electrokinetics to improve the strength properties of soft clayey soils. Hence the objective of this study was to investigate the influence of electrokinetic (EK) processing on the compressive strength aspects of two rehabilitated soil by experimental models. Unconfined compression tests were performed on untreated (original) soils and EK-processed soils.

The results revealed an increasing trend with soil compressive strength with time of processing and voltage gradients, the increase following different rates. Under certain voltage gradients and processing times, this technique showed noteworthy strength increases of about 175% and 200% respectively. Under each testing condition, both soils gained strengths of at least 30% or greater.

The difference in strength can be explained by complex and interrelated mechanisms triggered during EK processing. These include:

1. Electroosmotic Advection: In open electrode configurations, the variation of water content during EK processing is mainly caused by electroosmotic advection. Reduction in water content may also occur as a result of natural drying and evaporation, a process affected by time, temperature, and humidity. Results show that less water means harder soil.

2. Electromigration: The transportation of charge ions and the interaction of ions with clay minerals could change the ionic concentration in the DDL as well as change the soil structure and strength.

3. Ionic Diffusion and Aging: Ionic concentrations will continue to evolve after the processing has stopped, as ionic diffusion generates a slow rate of change. In this stage, cementation bonds might still form, further increasing the soil strength. Soil strength may also be affected by natural drying and aging processes[32].

J. Lamont-Black et.al., summarized many studies about using electrokinetic technique for firming of soil gradients, EKG offers economic & environmental benefits by dewatering with electroosmosis, reinforcing, draining, and modifying soil. As a guide to designing, analyzing, constructing and verifying the stabilization of a strategically important and environmentally sensitive highway embankment, this paper provides a brief overview of electrokinetic as applied to failed slopes. When comparing the slope to an adjacent embankment that had been remediated with conventional soil nails a year earlier, the strengthening cost was 29% less and the carbon footprint was 40% less. The scheme received a Green Apple Award for excellence in sustainable construction and an Institution of Civil Engineers Award for Innovation following the repair[33].

Electrokinetic treatment (E.T.) encompasses both electroosmosis and electrophoresis. Under the influence of an electric field, electrophoresis is the movement of charged particles within the soil. When it comes to soft clay, this includes the movement of the clay particles themselves as well[34]. A key mechanism of the process is represented by the movement of both water and charged particles in response to an electric field.

This procedure was used when remediating contaminated soils (both dissolved phase and particulate matter removal). The remedy of contaminated soils (removal of both dissolved and particulate matter) [35] Soil stabilization has been proven to significantly increase the strength of the soil due to changes in plasticity, as the rearrangement of the soil particles leads to the soil forming a "fabric" thereby increasing the shear strength. [36].

Ding Han et.al. specify the detailed evaluation of electro-kinetic remedy of polluted top soils and deposits: machines, presentations and knowhows, an important part of improving the eco-environmental quality is remediating contaminated soil and sediment[35].

4.1 Difference between electro-osmosis and electro kinetic through soft clay

Both electro-osmosis and electrokinetic treatment use electrical fields to manipulate soft clay's properties. Although they share a common principle, their mechanisms and applications differ significantly[36].

Both electro-osmosis and electro kinetic definitions, mechanism and application were identified previously at this paper.

While both electro-osmosis and electrokinetic treatment use electric fields to modify soil properties, electro-osmosis emphasizes water movement, while electrokinetic treatment includes both water and particle movement., It is up to the user to decide whether to use one of the two techniques based on the specific applicational goals.

4.2 Electro kinetic and E.O. treatments elements effects on engineering and remediation of soft clay properties

Conducting a laboratory-based examination of electrokinetic stabilization of the volume change of expansive soils Jayasekera Samudra. This study aimed to investigate the volume change

characteristics and solute transport in electrokinetically treated expansive soils. Locally sourced expansive soils were collected from three sites in central Victoria, Australia for this research. Soil was added in layers within glass tanks (plan area 900 mm × 350 mm), after which the layers were compacted to a target density and moisture content representative of what would be found in the field. Direct current at 0.5, 1.0 and 2.0 V/cm for time periods of 3, 5, 7, 10 and 14 days were stimulated in the soil by inserting electrodes in the soil[37].

Ana T. Lima et al. starts to explore the estimating of Polycyclic aromatic hydrocarbons (PAH) which could remove from fine soil using E.O. and electro dialysis, (PAH) are enduring and hazardous pollutants that are challenging to eliminate from fine porous substrates such as clayey soils. This study investigates two electroremediation techniques for the extraction of PAHs from contaminated natural silt soil in Saudi Arabia and silty loam soil in the Netherlands, which has been subjected to tar pollution for over a century. The two procedures under consideration are electro-osmosis and electro dialysis. The latter is utilized for the initial elimination of PAH. The efficacy of the approaches is analyzed using these two soils, which have been exposed to varying PAH contact durations[38].

Nasim Mosavat et al presented the effects of electrokinetic processing to increase engineering properties for the very little permeable difficult soils, the study showed that the electrokinetic technique could done and accelerated by using non health harm chemical materials like lime or cement solution when using them at the suitable electrode zone the research summarized that further research needs to conduct for more clarification about this new method, the study also concentrate on the main two aspects affecting electrokinetic treatment first one was the state of the soil and the system design process, the factors relates with soil state were characteristics of the soil and minerals, moisture of soil and pore water pH and electro-conductivity (E.C.) however second aspects could be represented by power and current voltages, description of poles material and treatment money amount the study observe that all these parameters effects on the electrokinetic process within different ways for example the electrokinetic improvement was effective on where soil has clay fraction equal greater than 30%[39]. Where A research study on how vacuum electro-osmosis affects the removal and cleaning of dredged sediments from Tai Lake was carried out by Wencheng Qi et al., when dealing with metal-contaminated silt from environmental dredging projects, it's often necessary to do both reduction and remediation. The electric field has a lot of potential for use in combining reduction and remediation. A test system that can be taken apart was made based on the electro-osmosis, vacuum, and vacuum electro-osmosis methods used in this work[40].

5.Using E.O. for improving pile capacity, pile installation and bearing capacity of foundation

5.1 Using E.O. for improving pile capacity and pile installation

First, it is difficult to divorce in E.O.S. effects during pilling from the pile and effect of E.O.S. on the pile installation (steel and PC) as well as pile performance; Pile capacity; is the capacity of the pile to resist

the loads subjected to it but in many situations when piles distributed in soft clayey soil layer consider to have the capacity decreased than the load needed to resist to the induced load therefore many methods for improving soft clayey soils layers were applied and one method can be used was E.O.S.

There was crucial study conducted by Spangler, M G and King which deals with electric of solidified clays which next to aluminum side resistance piles by certain tests, the specific objectives of the tests were to determine the relationship between the clay content of the soils in which model piles were driven, the maximum increase in bearing capacity of the piles and the optimal quantity of electrical dealing to yield supreme bearing capacity , overall results gave that the bearing capacity in all tests raised to an extreme rate as dealing proceeded and that more dealing after this ideal quantity produced a noticeable weakening in pile capacity, then the effect of clay content on the dealing process on soil-pile model tests results which they proportioned directly, the optimal dealing was larger for cathode probes piles than anode probe piles.

Final results evaluation for the piles of the equal proportions and arrangement, the optimal quantity of electrical healing rises as the quantity of (0.002mm) clay in the soil rises as seen in Fig.V also at the higher (0.002mm) clay ratio the pile capacity reached to the higher value and finally the researcher noted that the optimal treatment was higher in values for negative piles than that for positive one's Fig.8[41].

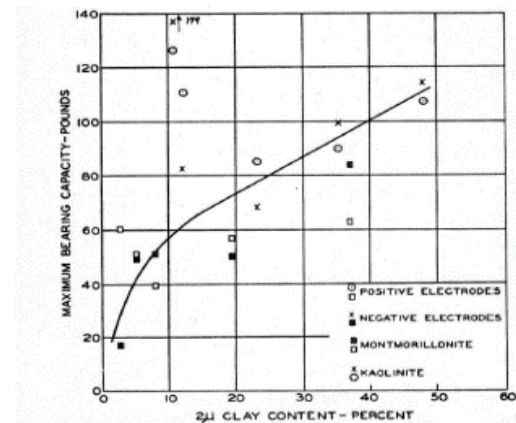


Figure 7. Clay content-maximum pile capacity relation [41]

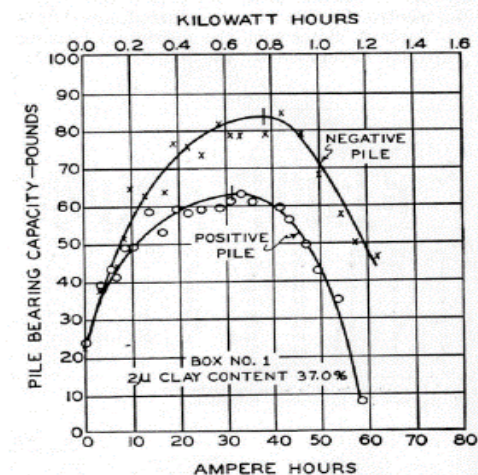


Figure 8. after MG Spangler (1949) [41]

To evaluate the Capacity of Friction Piles in Varved Clay increased by E.O. Soderman made his observation for exploring the occurrence of hydrostatic head for rough silty striatum at elongated friction piles gave less capacity than short piles embedded through soft varved clay; therefore, he decided to construct the bridge on short steel (H) section, the treatment works continued with pile capacity records, the study and compare the pile capacity and settlement after three hours, 5, 7, 8 and 41 days of E.O. treatment Fig.9 which raised the pile capacity from 30 to 60 tons then the observations continue for longer periods but the results not shown within this research, in summery Soderman refers to the clear increment in treated pile capacity if compared with not treated piles and the E.O. effect on straight varved clay layer was by quicken the degeneracy by pore water pressures during pile driving process [42].

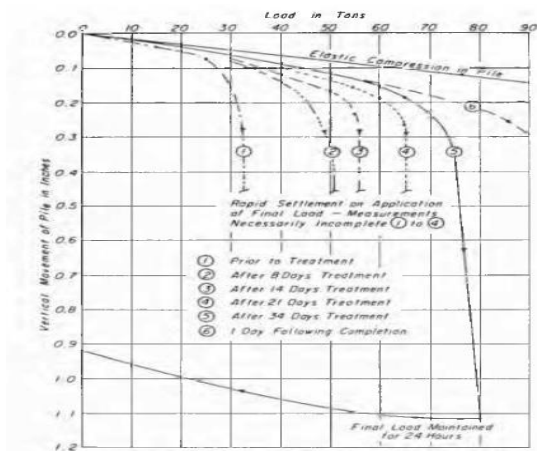


Figure 9. load tests on piles E16, East pier piles 12''*53lb H section 55 Feet long [42]

Victor Milligan (1994) continued above Soderman records in the same piles but for long time (three decades) with using the E.O. to increase friction pile capacity at this study deals with soft varved clay and loose silts extends for (100m) depth the records distinguished the increment in pile capacity especially for friction piles the piles were retested after 33 years and they found that their capacities not reduce, the increment that measured reached to doubling pile capacity (raised the pile capacity from 300kN to the 600kN), Fig.10 represent the observed pile load for the tested pile indexed as E-16, also the pile G-5 was selected to observe the effect of approximate three-decades on treated pile above as the Figure 6 refers it's clear that there were no effect on long period of time on total pile capacity Fig.11[43].

Two studies were available to demonstrate the increase of the offshore pile drivability using the E.O. technique Melvin I. Esrig and Woodward-Cyde (1978) by field applications on steel H-piles, they clearly were made reference that a reduction in the energy required by another half would be possible, and E.O. had proved its effectiveness on a sea site and the study 4432 R.M.El-Gamal and A.El-Sayed / HBRC Journal (2018) 14, 4429 4433 event of hydraulic jacking the E.O. could be an accurate field-proven source for thousands of blows, the research connect the E.O process with the water flow amount and the air manufacture by electrolysis, however the mathematical equation also used with their boundaries to explain a proposal case; as example one of site observations that the piles

were installed at approximate rate equals to 0.2cm/blow with no E.O. but the rate increased to 1cm/blow with using of E.O., the author used E.O. dewatering mathematical equation for pile installation issue as follows:

$$T = \frac{C_s t}{R_e^2} \quad \dots (1)$$

Where:

Cs: is the coefficient of consolidation of soil for swelling since positive pore water pressures result from electroosmosis.

t: is elapsed time; and Re: is the remoteness among the dishware or semi the remoteness among neighbored piles.

With respect to Fig.12, dimensionless pore water pressure U_e which is the proportion of the pore water pressure at any time u to the extreme pore water pressure U_f .

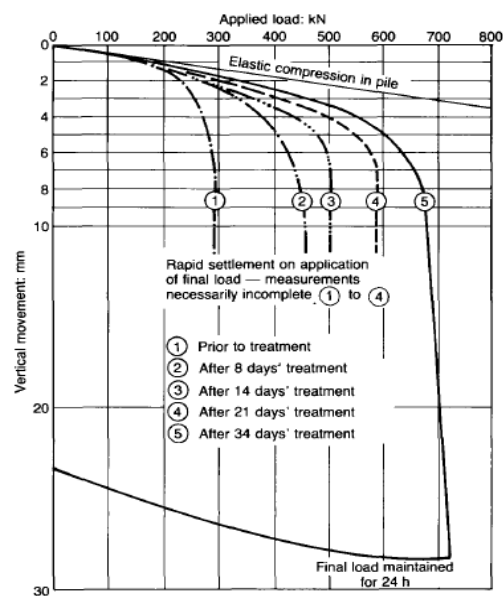


Figure 10. static axial pile load test on pile E-16[43].

$$U_e = \frac{U}{U_f} \quad \dots (2)$$

$$U_f = \frac{K_e}{K} \gamma_w V_{max} \quad \dots (3)$$

k_e is the coefficient of electroosmotic permeability which is measurable but approximately equal to $5 \times 10^{-5} \text{ cm}^2 / \text{volt-sec}$, K is the hydraulic permeability of the soil, a measurable property; γ_w is the unit weight of water; and V_{max} is semi the voltage induced among neighbored piles the overall electrical energy if plate poles were used.

For evaluate the electrolysis the author depends Faraday's rules, The creation of air on the exterior of a pile by electrolysis of aquatic will rise the pore pressure at the pile-soil boundary and assistance in pile installation, pile driving with electroosmosis will necessarily be accomplished at low voltages and with high currents. the relationship between voltage, V , and current, I , for a soil mass with a resistivity ρ , piles of radius R_w and spaced $2 R_e$ separately remains:

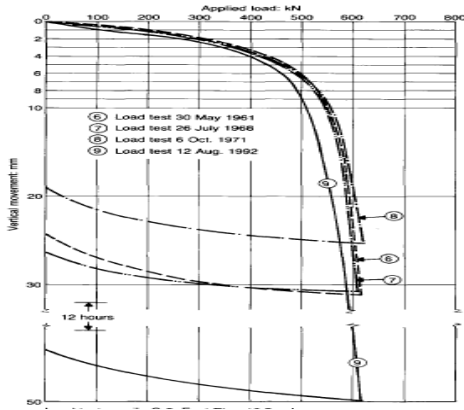


Figure 11. static axial pile load test (1961-1992) [43]

$$V = \frac{I\rho}{\pi L} \log_e \left(\frac{2R_e}{R_w} \right) \quad \dots (4)$$

Where probes are of the equal long dimension but not equal radius:

$$V = \frac{I\rho}{2\pi L} \log_e \left(\frac{2R_e}{R_{w1}} \right) + \log_e \left(\frac{2R_e}{R_{w2}} \right) \quad \dots (5)$$

Due to inducing current through soil media or texture the research refers to reduce the current value to 0.0032 amps/cm at this stream the soil temperature prevented to raised, in addition this study also founded that the electrolysis process guided the pile installation increment at the seaward zones[44].

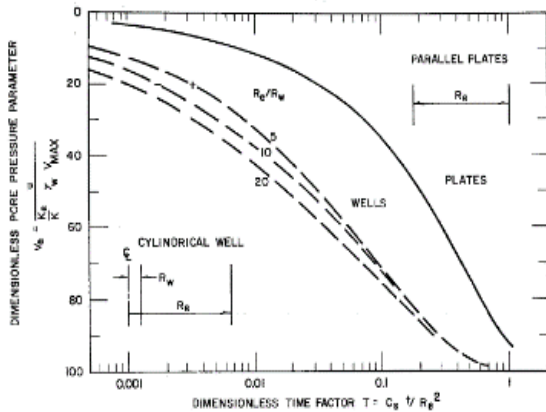


Figure 12. dimensionless time - pore pressure curves at face of the cathode, after Melvin I. Esrig and Woodward-Cyde (1978)[44].

For continuing research path above there were a study which concentrated on the site practice of E.O. to raise offshore pile installation carried out by W.L. Rose and B.R. Grubbs (1979) in fact the study mainly deals with steel H pile painting effects on pile installation process due to using H pile itself as electrode (anode in time and cathode in the other), painting technique in this research was regarded as innovated trail to improve utilizing E.O. through pile installation, the tests were done for coastal areas, it's important to refer that the field tests were done for both seaward and onshore piles, at this research there was another advantages of using E.O. in pile installation represented by overcoming pile body damage due to use high energy, installing great penetration piles for seaward stages, Dropping budding heave harm in pile groupings or to next to buildings , Dropping system through installation intermissions and

lessening pile barrier width because of lesser pile installation vigor supplies Fig.13[45].

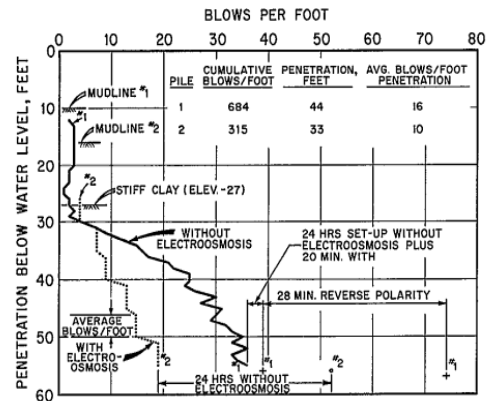


Figure 13. Result of E.O. driving and arrangement – 30 inches outside diameter piles 1 and 2 [45]

For the same period or near Butterfield, R. & Johnston, I.W. (1980) write on the effect of E.O. on metallic piles in clay, at the research there were many E.O. advantages proved like permanent pile capacity development for the treated pile, reducing pile penetration resistance, the author in addition refers that there was some sign according to the lab or little prototype tests that pile capacity could raise tan untreated even after E.O. off however the study proven that E.O. had no clear effect on pile end bearing load which differ than other studies, the research explored also E.O. mechanism clayey consolidation.

Research measurements were depending many radial stress which supported by average total clayey radial stress through pile shaft and the radial stress values ranges from four to five clayey undrained soil shear strength Fig.(14), in conclusion the lower scaled sample consolidation period scale will be round twenty fifth times faster than that used for a distinctive prototype pile, the study founded that real computed interface angle of friction (δ) which equal to $\tan^{-1}(\tau/\sigma_r)$ was backing post pile driving, U_0 (pore pressures), very low cohesion and contingent.

limited shear pressure measurement for both treated and untreated piles model allowed effective roughness angle (δ') adopted as (130) for pore pressure difference ranged between (4Cu) to the (5Cu) through E.O. pile driving. At the end the author recommended to reduce the adopted value of σ_r' and δ' .

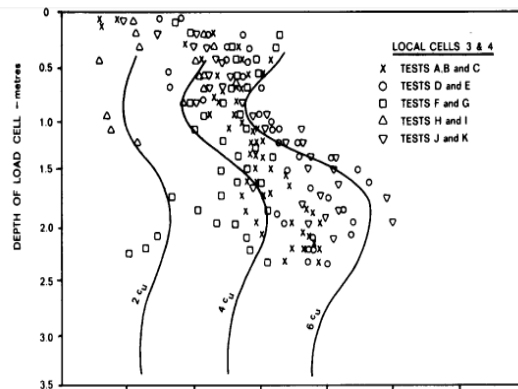


Figure 14. Total radial stress acting on local load cells for different penetrations for tests A to K [46]

There was other research direction in discussing the properties of probes constituents and current intermittence through E.O. done by E. MOHAMEDHASSAN and J. Q. SHANG, the study use a marine silty soil inside soil cell after adding 6 couples of probes are experimented to evaluate voltage drop at between soil probes boundaries and for predicting the coefficient of E.O. conductivity (K_e), the results gave that the drop in voltage depends mainly on anode material however in the metal positive terminals the drop records smaller amount than Carbone ones, in the other hand the K_e values was not depends on probe materials but on the electrical intensity (E) for the soil current medium carrier (marine silty soil), the research continued about the effect cut and connect current which gave more E.O drainage than continued current for constant voltage, the study conduct the test for both open and short circuit made a comparison, the K_e records extreme value when the current was worked for two minutes and cut one minute for open circuit mode Fig.15[46].

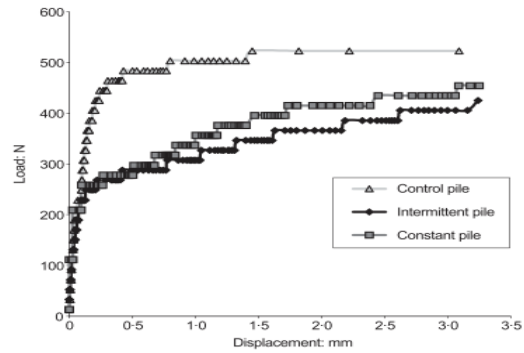


Figure 16. Outcomes of axial pile load capacity[47]

As predictable, the amount of vertical pile displacement of the preserved piles through the two days was high, tracked by more vertical displacement, nevertheless at a lower amount of overall final displacement of the piles Fig.17.

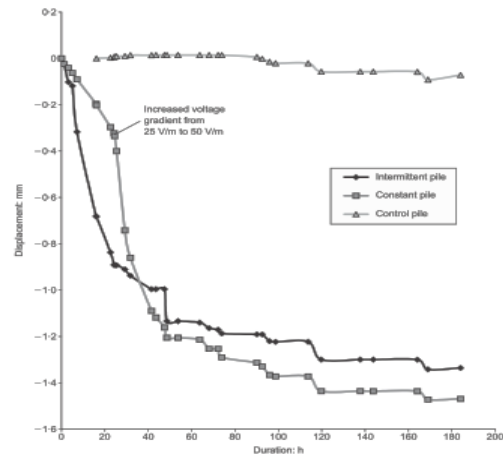


Figure 17. Pile displacement through E.O. healing

Finally Table 1 could be summarized most of gathered data and conclusion[47].

Table 1. Ultimate axial and lateral pile capacity and adhesion factor [48]

| Pile | Treatment time: h | Axial pile capacity: N | Lateral pile capacity: N | C_2 : kPa | Percentage increase based on average of control piles% |
|------|-------------------|------------------------|--------------------------|-------------|--|
| F | 1.2 | 1850 | - | 4.9 | 33 |
| A | 4.3 | 1990 | - | 5.3 | 44 |
| G | 12.0 | 1970 | - | 5.1 | 39 |
| E | 24.0 | 1880 | - | 4.8 | 31 |
| J | 72.3 | 1500 | 805 | 3.7 | 1 |
| B | - | 1600 | - | 4.3 | |
| C | - | 1170 | - | 3.5 | |
| D | - | 1300 | - | 3.8 | |
| H | - | 1420 | - | 3.1 | |
| I | - | - | 903 | - | |

Figure 15. Typical k_e planned in contradiction of cut pauses for exams carried out on both open circuit, short circuit and continuous direct current [46]

Another research on the effect of E.O. remediation on piles compression and pull-out capacity in this treatise E.O. process was subjected to rise the axial and sideways capacity of piles driven in a weak sensitive clay in a lab testing package. To test the E.O effectivity two models were conducted one of them minor model (worktable scope) and the other was depends on the first model results to conduct the huge model testing package, the soil samples in two models was preserved, one with endless straight current and the another with irregular current, and the 3rd was not preserved and was used as the controller, The output collected data gotten from the limited size tests displayed that the pull-out capacity of the piles in the dealing cells reduced but their sideways capacity enlarged, associated with the controller pile. The decrease in pull-out capacity was associate with over amount of healing of the soil in the surroundings of the pile, made soil contraction and parting at the pile-soil boundary. The over amount of healing was perhaps because of extreme healing energy established in a more voltage incline and an extended healing period, the output data gained from the axial load examinations displayed that the healing had enlarged the pile ability to resist load more than that of the controller piles by equal to 45% Fig.16.

The latest two researches were conducted by using vertical E.O. to discuss soil pile interaction and to enhance pile bearing resistance by Fangtao Zhong et.al. [48] and Yunliang Cui et.al. respectively[49].

In the first research, the muddy weak soil was selected as the texture screen, and the vertical E.O. sample was carried out beginning at upper toward lowest pile sample shaft, and also within

reverse direction (lowest toward upper sample edge). The soil cohesion values were observed through the soil which locate next to the pile shaft previously and next of E.O. process by recording the soil moisture, soil superficial settlement, electrical current consumed, soil overburden pressure at the pile tip, and additional coefficients; The static load test was done on the pile after E.O. and associated with the non-treated collection to compare the static properties of pile-soil interface subjected to vertical E.O., it is appearing that the maximum pile capacity to resist static loads of the no.1 pile located at the side of soil container and the No. 3 pile located at the mid of the container has been enlarged by 3.7 and 4.5 ones, correspondingly, when E.O. stopped, and the maximum pile capacity of the No.3 mid pile is more than that of the No.1 terminal pile, with a rise ranges from 7.7% to 9.2%. The effect of upper to lower direction E.O. was more than that for opposite vertical E.O., the maximum carried load for pile No.1 and the No.3 mid one was improved by the ratios of 18.5% and 16.8%, correspondingly.

The Soft soil around the pile shaft: Beyond and after E.O was experimented by disk blade and also was D.S. (direct shear) experiment that was done and Table 2 shows the results that for lower to upper E.O process the data shows that; for cohesion (c) for kPa units for the soil round the No.1 terminal pile and the No.3 mid one increased by 0.8 times and 1 times respectively on the other hand, for upper to lower E.O the for cohesion of around the No.1 terminal pile and the No.3 mid pile is increased by 1.2 times and 1.3 times respectively. Once E.O. was completed, the soil in the pile-shaft side could be improved very well.

Table 2. Evaluation of soil cohesion which lies at the pile sides previously and next to E.O. [48]

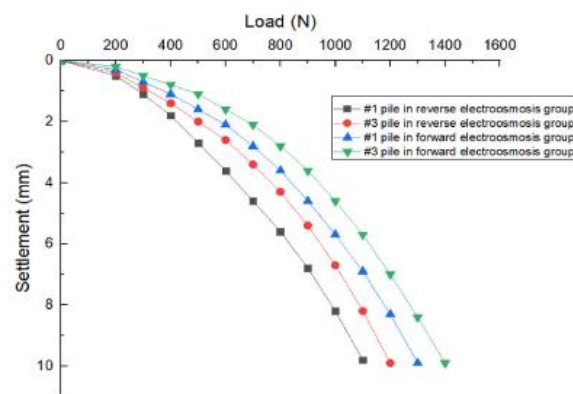
| Indexes | Before E.O. | The #1 side pile in inverse E.O. set | The #3 central pile in inverse E.O. set | The #1 side pile in forward E.O. set | The #3 central pile in reverse E.O. set |
|--------------|-------------|--------------------------------------|---|--------------------------------------|---|
| c(kPa) | 3.4 | 11.9 | 12.8 | 14.1 | 14.8 |
| $\varphi(o)$ | 4.8 | 8.7 | 9.4 | 10.6 | 11.1 |

For the more details about maximum pile bearing resistance Fig.18 clarify that maximum mid pile capacity No.3 was much than that of No.1 terminal pile these piles were subjected to the both E.O. types and at the lower to the upper type maximum pile capacity No.1 side pile was equal to 1050 N, and that of the No.3 pile was 1147.1 N, therefore the increment value was 9.2%, in the other E.O. direction for overall group, the capacity of the No.1 pile was equal to 1243.8 N, and that of No.3 pile was 1340.0 N, with an increment value of 7.7%. The effect of first E.O. direction was more than that of other (upper to lower E.O.) direction, if comparing with opposite E.O., the No.1 pile and the No.3 mid pile in frontward E.O. enlarged within value of 18.5% and 16.8%, correspondingly.

For comparing between not E.O. treated pile collection Fig.19 was drawn it seems that maximum recoded pile capacity solo pile located at not E.O. treated pile collection was 245.8 N. for the results of the No.3 pile gave that the pile's capacity of opposite E.O. and

frontward E.O. enlarged by 3.7 times and 4.5 times, correspondingly[48].

At the second study was reported the upright E.O. process to increase the piles capacity through maritime clayey soil in soft state, the E.O. process conducted with respect the current electrode's location in two categories upper to lower E.O. when positive electrode at the top and negative one at the bottom when reverse electrodes direction the second category was indicated as lower to upper E.O., with this process the testing of piles was conducted without any E.O. for comparing with piles which not treated Fig. 20.



Figure

18. Load displacement relations of both frontward and opposite E.O. pile collection[48].

The results gave that the capacity of pile subjected to the upper-lower E.O. was 16.7% more than lower-upper E.O. Fig.19 and Fig.20 also the drained water quantity due to E.O. was 41.69% more in upper-lower E.O., if this process emulated with the horizontal E.O. for areas near pile shaft the study found that upright E.O. gave more draining velocity than horizontal E.O., much soil consolidation amount and little improvement in pile capacity therefore and according to the simplest requirement for upright E.O. it seems interested for more applications.

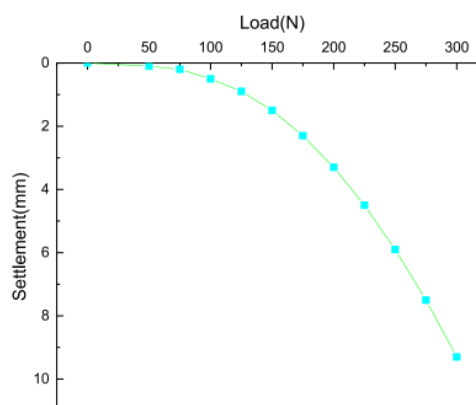


Figure 19. Load displacement relation of not E.O. pile collection [50].

Through this study like other studies the prepared soft clay with water content near liquid limit and the electrodes were consisted from metallic rings rounds outside pile shaft, the power supply source has a voltage of 36 volts and initial current was 2.3Ampire.

For analyzing data results the researcher deals with soil moisture content at areas in around positive and negative electrodes, E.O. drained water quantity, variation of consuming electric power, soil superficial vertical displacement, changing in end bearing pile pressure, soil cohesion and development of surface cracks[49].

Khairul Nizar Mohd Nizar and B G Clarke reported main notes on Electro Osmotic Piles, the paper presents a proposal of electro osmotic piles, akin to soil displacement ground improvement systems; however, it employs electro osmotic treatment to enhance ground stiffness by diminishing water content through electrodes configured as prefabricated vertical drains. The drains are positioned vertically to create a grid of anodes and cathodes. The cathodes function as the drains, while the anodes serve as the focal points of the 'piles' where the greatest enhancement in stiffness transpires. Laboratory testing employing various configurations, treatment durations, and voltages demonstrated a balance among the enhanced overall capacity of the ground, system efficiency, and operational energy. This idea enables the prediction of final capacity based on the improvement process, unlike existing ground improvement approaches[50].

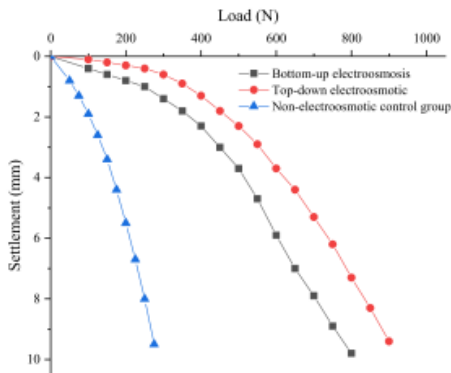


Figure 20. Load displacement relation of many conducted tests[49].

B.A. Nikolaev conduct sperate textbook titled as pile driving by electroosmosis, its crucial study that refers to many piles used with E.O. through some of projects, the effect of E.O. on soil, effect of E.O. on soil while pile derived , influence of mineral composition, effect of electrode areas, on rate of pile driving, vibro-sinking of reinforced tubular pile restoration pile capacity and the evaluation optimum pile penetration through E.O. represents main topics which this book deals with.

In final results there were many reasonable notes about using E.O. which could accelerate the process of driving pile which also based on temporary decrease in electrical resistance of the ground to the sinking of a cathode pile, the text after test the two pile E.O. categories indexed as unipolar and bi-polar Fig.21

recommends that pile should be sunken by the unipolar scheme and the wooden piles may be driven with the aid of E.O. bipolar category.

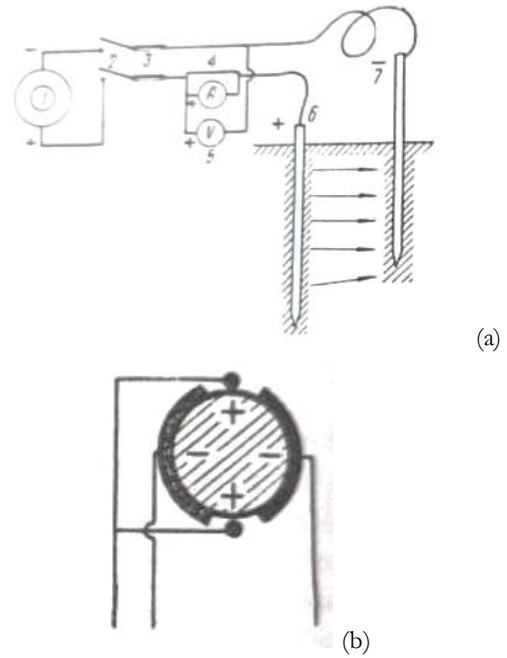


Figure 21. E.O. electrodes categories (a) unipolar, (b) bipolar [51]

For the not E.O. treated pile collection the comparison Fig. 19 is extracted maximum recoded the load of a solo pile that was stacked not E.O. treated piles was 245.8 N. Maximum in opposite E.O and frontward E.O It appears that that the pile load of the pile number 3 pools was 3.7 times and 4.5 times expanded for the not E.O. stacks and piles SCHED table of the opposite E.O. stacks and piles.

For wooden piles the text refers clearly when driving wooden piles using E.O. needs less hummer blows and gave quick and more penetration per blows rate than normal piles; due to that conclusion top of piles were less deformed Fig. 22 [51].

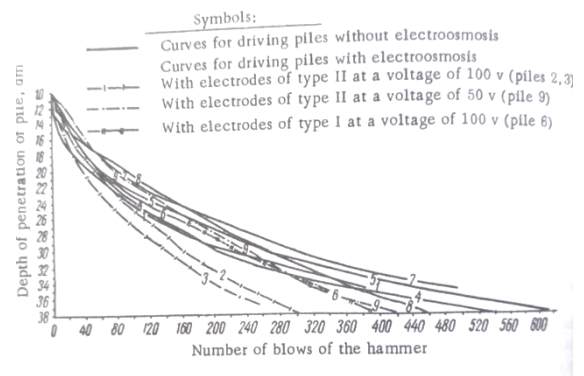


Figure 22. relation between hummer blows and penetration depth for some of wooden piles[51].

5.2 Using E.O. for improving shallow foundation bearing capacity

The use of electro-osmosis to solve a shallow foundation issue in a Norwegian quick clay was investigated by L.Bjerrum et al. The paper details a situation in which the application of electro-osmosis increased the strength of a very soft quick clay from less than 1 t/m² to an average value of 4 t/m². Fig. (23). An attempt is made to paint a profile of the impact of electro-osmotic treatment on a soft clay

based on observations obtained both during treatment and at the excavation site. Measurements of pore pressures and settlements at different depths are among the observations, as are analyses of the treatment's effects on the clay's characteristics. An alternate building method that was taken into consideration was the E.O.[1].

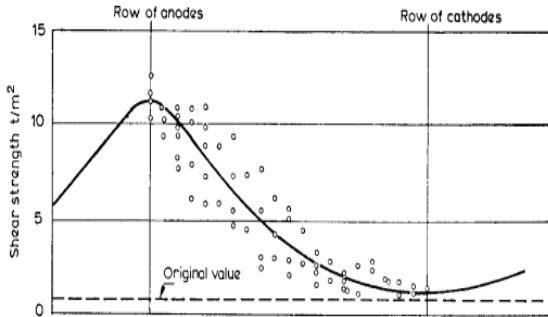


Figure 23. Results of vane borings and sampling carried out at a depth of 4.5 m below ground surface during the excavation period (approx. 50 days after the end of the osmosis treatment)[1].

For an estimate of the amount of water which had to be squeezed out from the clay to produce this increase in strength it was assumed that consolidation by electro-osmosis would have the same effect on the shear strength of the clay as consolidation produced by an increase in effective stresses.

Fig.24 shows the relationships consolidation pressure-water content and water content-shear strength used for the design of the installation[1].

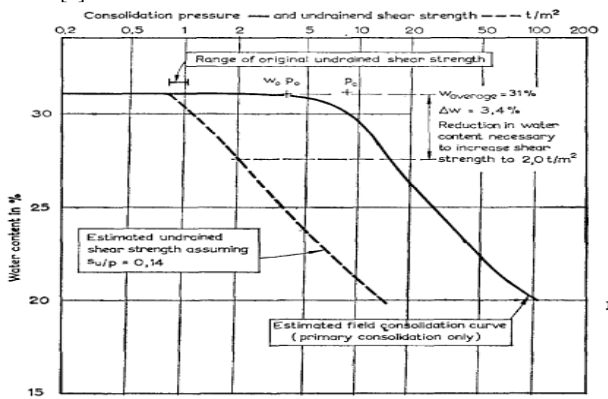


Figure 24. Relation between water content, consolidation pressure and undrained shear strength representative for the soft clay at a depth of 46 m. Used to estimate the reduction in water content required to increase the shear strength to 2 t/m2 [1]

6. Studies analysis and research gap

This review research is conducted in general for explained the effect of using E.O. soil improvement method or technique to measure and evaluate soil shear strength, physical and chemical properties after treatment, for first part of researches the ke can take as constant[7] value after E.O. process and liquidity index raised[1], the soil temperature which treated by E.O. also raised like soil shear strength and consolidation rate accelerating and reasonably the moisture content reduced, both soil resistance and interfacial resistance after E.O. decreased[19] [12] but at another study E.O. efficiency relates within soil resistant behave within inversely

way[15], at another study which deals with effect of electrode distribution and their materials the study finding that using copper gave more increment in soil resistant[9], however at another research finding that use dewatering by E.O. significantly diminishes resistance at the soil cathode[24], all that altitude may returns to the lowering soil water content due to E.O. at anode.

Other engineering soil properties related directly with decreasing of soil water content also, soil cohesion raised around pile shaft from about 4 to 11 kPa after E.O. [15]with near or same manner for another researches[1, 10, 12, 13, 21, 28, 29]

E.O. also was elevated the treated soil PH[5] and raised electrical conductivity value [10] and the technique lowered soil electric resistant[12], the PH was decreased near anode area also[16, 46].

The efficiency of E.O. have clear relation within clayey soil content which required clay content 30% or more[39, 41], another studies discuss power consumed with soil improvement values[19] the power losses founded needs to manage with respect to require soil properties[8], power intermittence could increase E.O. efficiency and reduced energy treatment cost and enhanced dewatering efficiency[23], for studying effect of poles material on both E.K. and E.T. showed that using steel, iron and copper it would be more effective than ones consists from black carbon, lead and platinum[9, 11, 39].

The effect of E.O. on overall pile capacity was doubled its value twice time with certain conditions [42] also the same group researches deals with same pile to find that treated pile capacity not decreased within long period of time[43], other studies prove that cathode piles has more capacity than anode ones, electrical power proportioned with clay content and both of them directly cause pile capacity increment when clay fraction increased[41], other researchers used pile penetration rate, consumed power or energy, drained water and amount of gases due to E.O. as main parameters effects on using E.O. at pile installation process; he founded that the electrolysis process guided the pile installation increment at the seaward zones[44], related with the last research the other was explored effect of painting steel pile shaft on pile installation through using E.O. due to overcome expected pile shaft bending or twisted[45], the most interested theoretical study for voltage ranges about thirty to ninety volts that gave pile bar load capacity increment by (200%) for anode pile but the percent recoded decrement for more than five times for cathode one, In general, the research refers to there was no reasonable result on pile end bearing after E.O. process[52], at another study the Ke records extreme value when the current was worked for two minutes and cut one minute for open circuit mode[46], for using of vertical E.O. through pile shaft there was two interesting researches which concluded that for the results of certain pile gave that the pile's capacity of opposite E.O. and frontward E.O. enlarged by 3.7 times and 4.5 times, correspondingly in the first study and second one results gave that the capacity of pile subjected to the upper-lower E.O. was 16.7% more than lower-upper E.O. Figure (17), also the drained water quantity due to E.O. was 41.69% more in upper-lower E.O.[49].

To observe the clear effect of E.O. on pile driving, separated study founded that pile should be installed by the unipolar scheme and the wooden piles may be driven with the aid of E.O. bipolar category

figure (19), Field tests show for pile depends as anode the soil around pile shaft will dry in rapid way, this increment would also increase friction between pile and neighboring soil and the shear resistance raised; therefore the E.O. method could use for rapidly recovering soil strength around driven anode pile[51], finally there were few studies conducted to on the effect of using E.O. to improve shallow footing bearing capacity, with the technique bearing capacity already raised due to soil shear strength increment within four times than untreated soil samples[1].

After reviewing in detail most of studies conducted on the E.O. method path it's clear that main research gap could be recognized as the changing of soil properties around pile shaft during pile driving and these effects on overall pile behavior under static loading process, coating which used for steel pile shaft surface and its direction to paint pile shaft lateral surface area partially[45], effect of E.O. on many other soft clay properties like liquid limit, plasticity index, optimum soil moisture content, lateral pile capacity, angle of internal friction and coefficient of permeability; while the influence of E.O. on stiff and medium clayey soil could also represent new promising approach.

7. Discussion and conclusion

At the end of this review the E.O. technique has a wide range application in soil mechanic, foundation and environmental disciplines, the main points about could be concluded below for using E.O. and E.K. in weak soil treatment and pile driving works through weak soils which represented by soft clayey type in common:

1. Although this technique starts as a method of dewatering water but the site observation indicate that method could use in soil improvement within efficient in both cost and time consuming especially for soft clayey soils.
2. Using of E.O. method within certain condition relates with both soil and E.O. elements can improve the soil shear strength in dramatic way; and on another side after using this technique the consolidation will accelerated.
3. The studies and researches deal with this electrical process to explore the effect of energy, electrode material, electrode configuration, hydraulic conductivity, physiochemical changes, soil resistance, volume of gases, drained water and so on.
4. Main soil engineering properties which represented by water content, shear strength, consolidation parameters and soil settlement founded they effected by E.O. treatment.
5. There were many applications which would made using E.O. method has a priority among many soil improvement methods when the site contains soft and medium to soft clayey within sufficient depth, these applications were slope stabilization, foundation improvement, land reclamation, pile installation and improving pile capacity.
6. Due to all above points the review discussed many of case studies which applied this method and most of them founded the time factor not altering the improved soil property.

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