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Influence of Voltage on Pore Water Pressure for Soft Soil Treated with Electro-Osmosis Technique

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ABSTRACT

Geotechnical engineers have a difficult time working with soft soils because they take so long to reach their final settlement and drain water under pressure. Granular columns and other modern technology are just two of the many methods utilized to hasten this leveling. In this study, the alteration of clay soils with a granular column and the evacuation of water by an electric field were replicated using 2D engineering and a finite component. solid mechanics and electrical interfaces are built using the drag interface. Mohr-Coulomb relied on a granular column and fine clay soil at the mechanical contact and employed electro-osmosis to describe the model's electric field's impact. For a period of six months, the pore water pressure for the fine clay soil was calculated. The result showed that when the electric current is applied with a voltage (5 v) the pwp in soil increases in first two months and then begins to gradually decrease, reaching in sixth month (120 kPa) and when applied voltage increases (15 v) the pwp decrease in the first two months from the previous ratio of voltage then it begins to gradually decrease and reaches in sixth month (70 kPa), When applied voltage increases more (30 v) the pwp in the soil decreases in first two months from the previous ratios of voltages, then it begins to gradually decrease and reaches (40 kPa), The percentage of water leaving the soil when an electric current is applied from (5-15 v) was (64%) and when voltage increased to (15-30 v) became (75%) which means the applied voltage increases, cause more water is discharged from the soil. The soil settlement also increases with an increase in the voltage, as the improvement percentage and the water exit from the soil (50%) at (5-15 v) and (71%) at (15-30 v).

1. Introduction

Most of central and southern Iraq's soil is soft to very soft, and clayey soil, especially in areas near marshes. In these areas, several projects are planned. It is expected that more than 1,400 kilometers of new railway network will be created and the existing network will be repaired [1]. Clay is a fine-grained natural soil or rock material, and its volume changes considerably when subjected to load. The water content of the clay may be greater than its liquid limit. However, clay is plastic due to the influence of high moisture content and becomes non-plastic and hard after drying [2], this increase in moisture content may come from Rain, flood, sewer, leaks, or surface reduction evaporation when buildings or sidewalks cover an area.

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Mainly from clayey soil causing cracking and fracturing of Pavement, railway, highway embankments, roads, foundations, and Channel or reservoir lining [3].

The water content between the plastic limit and the semi-solid is called the plastic limit (PL), and the shrinkage limit (SL) is the state where the loss of water does not cause any volume change [4].

Water can significantly impact a soil's ability to remain stable. Since soil stability and strength depend on effective stress, changes in pore water pressure directly affect these properties. Dewatering is a method for altering soil's water content and pore water pressure to improve soil behavior. To improve the soft soil, dewatering can be done using prefabricated vertical drains (PVD), surcharge, or preloading. Vertical sand or gravel drains can also be used [5].

Granular columns are widely used in geotechnical engineering to reduce settlement, increase bearing capacity, accelerate consolidation, and decrease liquefaction potential [6]. The model was evaluated on granular columns with and without reinforcement at various depths, including short, floating, and fully penetrated columns. The column appears to be in failure mode because of the diverse configurations and reinforcements used, exhibiting a tiny difference. They concluded that providing encasement is the optimum solution for end-bearing columns, while horizontal strip reinforcement and encasement for floating columns change nothing [7]. The footing load was given using a sand mat in a temperature and humidity-controlled setting, and the column was put in the center of the massive tank. They discovered that long stone columns (reinforced or unreinforced) always failed by bulging but floating or end-bearing stone columns always failed by punching.

Under embankment loading, the behavior of completely reinforced and unreinforced clay and geogrid-encased columns was statistically examined. The clay's behavior is studied using consolidation analysis. The foundation's bearing capacity increases when the surplus pore water pressure is lowered. There is even more utility with encased columns. Examine whether the stress concentration created in columns has a significant impact on soil consolidation speed [8].

Porous water can be transferred from the positive electrode to the cathode along with other materials by providing an external electric field to the soil mass. The unification occurs due to the magnetic movement of the cations Many field tests and laboratory experiments for this technology [9].

Electroosmotic consolidation has been utilized frequently in geotechnical engineering since Casagrande (1949) initially employed it to increase the stability of fine soils, notably during slope stabilization, soft ground improvement, tailing dewatering, sludge treatment, and other processes [10].

[11] constructed a two-dimensional finite-difference model by analysing subsurface settlement and undrained shear quality to quantify excess pore water weight during electro-osmosis,when cathodes are introduced vertically, the anode's impact is similar to that of a relocated column, such as a vibro-compacted stone column, and the excess pore weight produced at the anode by the voltage contrast is similar to the increase in spiral stretch caused by the installation of a granular column. Thus, a lattice of anodes and cathodes set vertically could have an effect similar to that of a lattice made of stone columns.

Reuss first described the principle of electro-osmosis in 1809. He observes that water flows through the clay when a direct current is passed Application, as shown in Fig.1 below [12].

[13] water will flow from the anode to the cathode with the influence of the applied potential. This flow is attracted by anions to the anode and cations to the cathode and during the migration process, the moving ions will carry the surrounding water of hydration since the cations in the negatively charged clay particles is much higher than Anions, therefore, pore water is drawn from the anode to the cathode. Electro-osmosis depends on electroosmotic conductivity and applied voltage.

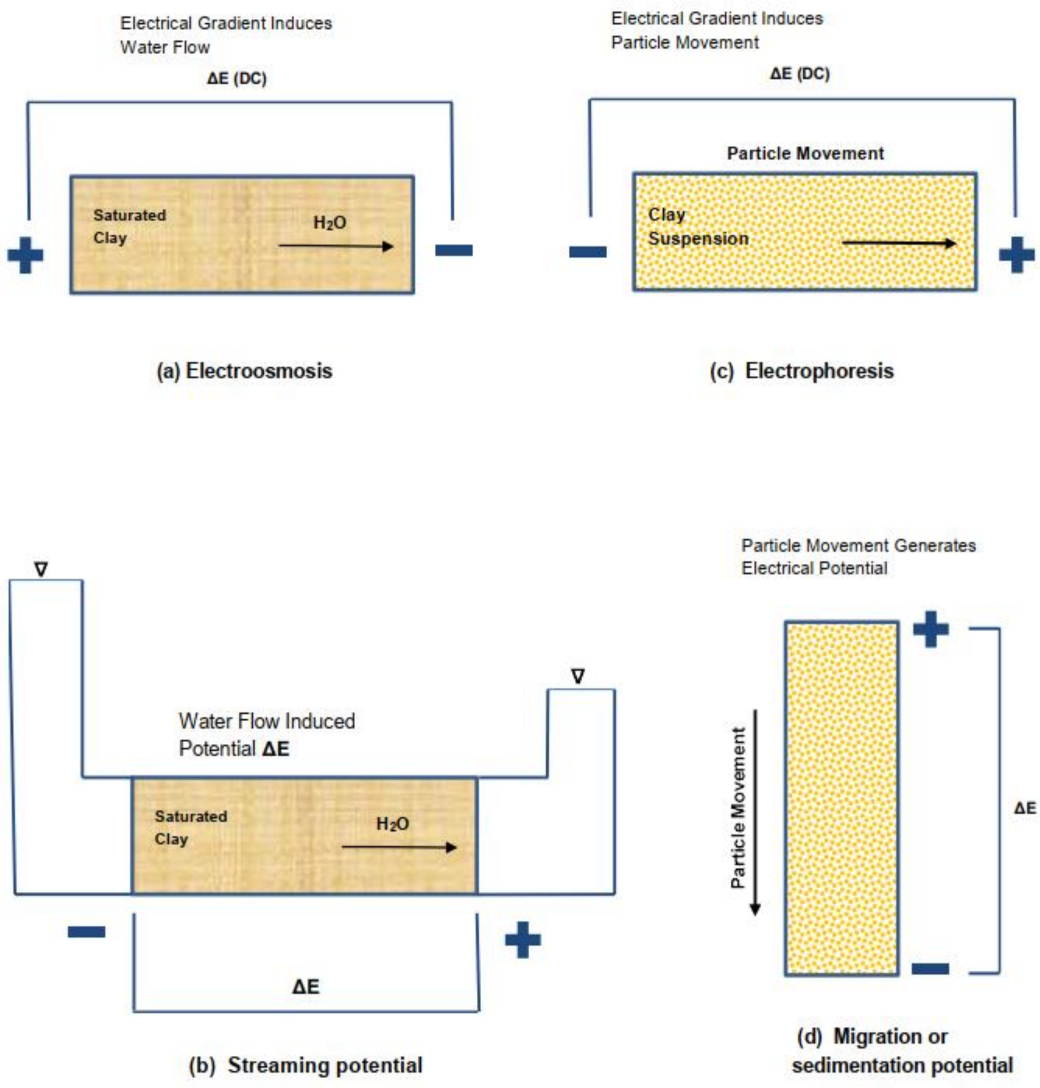


Figure1. Electro-osmosis phenomena in soil [12]

A numerical model of the electro-osmosis setup was created for this work. To calculate the temporal progression of the weight, electric field, pore water pressure, settling, and distortion within the soil and columns planted in it as a result of the connected stack, a FE view was created in this manner to simulate electro-osmosis that can be knob in two geometric measurements.

2. Methodology

2.1 Soil material

The model create for the simulation of soft soil to be treated by granular columns and electric current to speed up the process of water leaving the soil in a period of six months, there is a need for some of the input options to execute a FE analysis using the COMSOL program, A numerical model was used to create a soft clay soil as shown in Fig.3 below, with dimensions of (8*6) m² in which granular columns of (8 m) in length and (1 m) in diameter were inserted, along with anode and cathode electrodes of (4 m) in length and (0.1 m) in diameter embedded in the granular columns with applied various voltage (5,15, and 30 v), the load applied to the soil as earth dam with a (36 kN/m²). Boundary conditions of this domain are fixed in the bottom, in the right and left rollers, and in the top boundary load. Fig.4 below shows the finer mesh of the soil structure with granular columns and the material properties are shown in Table 1[14].

2.2 The Concept of Electro-Osmosis

Electro-osmosis is the process by which an electric current causes a stream of pore fluids in soil. The electroosmosis principle is depicted in Fig.2 below [15]. The electrolysis process is influenced by the chemistry of soil water, gas generation, and electrolytic redox productivity.

Due to the voltage difference between a positive anode and a negative cathode, the voltage refinement recreates a negative pore weight combination caused by an outside stack at the anode inside the soil. The degree of union will alternate between the cathode and anode, with the anode taking the lead, because the anode is closed, meaning there is no pore liquid regeneration, and the cathode is functioning as a deplete. If the anodes are introduced vertically at that time, the effect around the anode can be compared to the impact of a relocation column, such as a vibro-compressed granular column [16]. Calculative analysis was carried out using COMSOL MULTIPHYSICS, a finite element tool. This study's multi-field coupling numerical simulation of electro-osmotic solidification is based on. The condition for Pore water is as takes after:

$$\nabla.(Kh\,\nabla H + Ke\,\nabla V) = -\frac{\partial \varepsilon v}{\partial t} = \frac{\partial}{\partial t}(\nabla.u) \qquad (1)$$

Kh and Ke are pressure-driven conductivity and electro-osmosis conductivity tensors individually; H and V are added up to water head and voltage; εv is the volumetric strain of soil mass; u is the vector of soil mass uprooting. Biot's theory characterizes the stress-strain behavior of soil [17]

$$\nabla^2 u + \frac{1}{1-2v}(\nabla.u) - \gamma w.\frac{2(1+v)}{E}\nabla(H-z) = 0 \qquad (2)$$

where v is the Poisson's proportion, E is Young's modulus, z is the height head, and γw is the water unit weight the run the show of preservation of electrical charge can be utilized to determine the overseeing condition for the electric field.

$$\sigma e \nabla^2 V = Cp\frac{\partial v}{\partial t} \qquad (3)$$

in which σe is the electrical conductivity tensor; Cp is the capacitance per unit volume

Eqs. 5 to 7 combined to explain the electro-osmotic consolidation linked process.

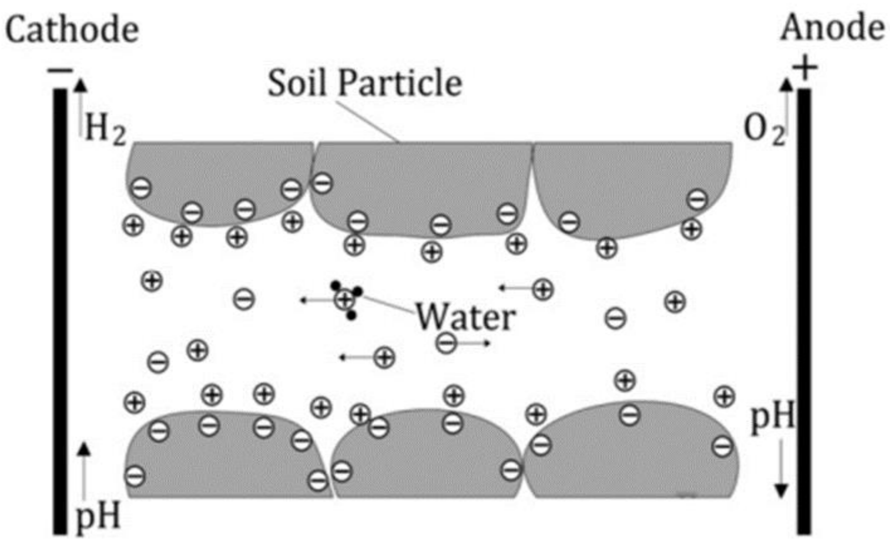


Figure 2. Principles of electro-osmosis [15]

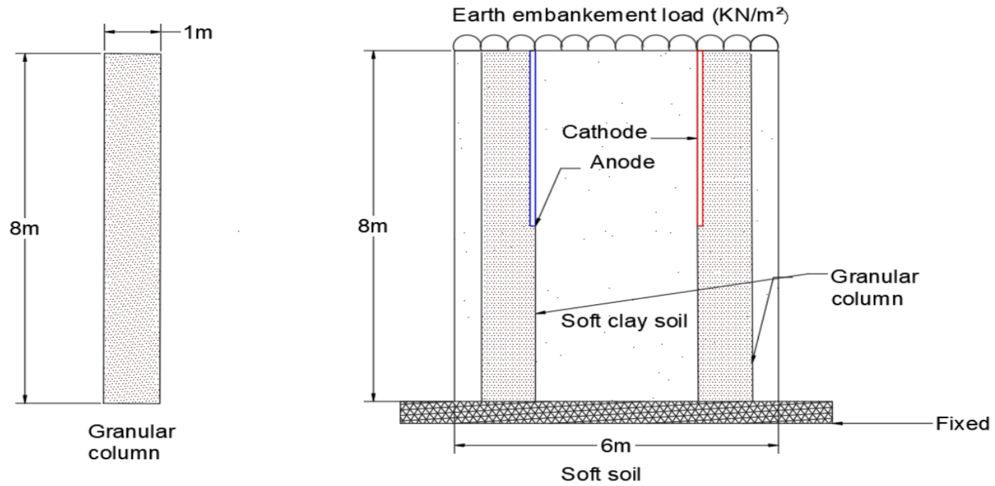


Figure 3. Geometry modeling of soft clay soil embedded granular column [14]

Table 1: Materials soil parameters adopted for FEM analysis [14]

Parameter	Units	Soft soil	Granular columns
Material model Loading	_	MC Undrained	MC Drained
Young's modulus	(kN/m²)	2000	55000
Poisson's ratio	(υ)	0.4	0.3
γunsat	(kN/m³)	15	18
γsat	(kN/m³)	16	19
Porosity	_	0.5	0.3
Compressibility of fluid	(1/Pa)	0.001	0.001
Horizontal permeability Kh	(m/day)	$7.36x10^{5}$	12
Vertical permeability Kv	(m/day)	$3.68x10^{5}$	6
Relative permittivity	_	0.9	1
Cohesion	(kN/m²)	35	0
Friction angle	(φ°)	1	35

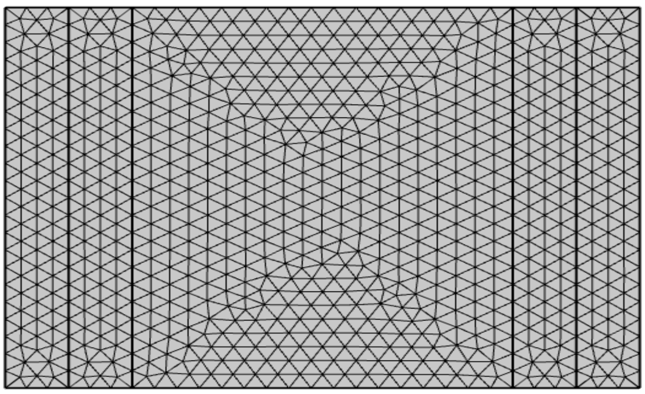


Figure 4. Finer mesh of geometry soft soil model and granular column

3. Results and discussion

Since soil stability and strength depend on effective stress, changes in pore water pressure directly affect these properties electroosmosis is a method for altering the water content and pore water pressure of soil to improve soil behavior. To improve the soft soil, a granular column with electroosmosis can be used. A porous material that has been soaked with water will migrate toward the negative electrode (cathode) when a direct current is supplied to it, this occurrence is known as electro-osmosis. The ions with positive charges produced by applying a direct current will cause the water in the soil's pores to flow out. Since water cannot access the system's anode (positively charged electrode), the soil's water content decreases. The soil is consequently consolidated as a result. Due to its ability to reinforce the soft, saturated clayey soil and expedite consolidation, electro-osmosis has an advantage over other methods [18].

Figure 5 shows the relationship between pore water pressure and time in months for the length of granular columns (8m) and (1m) in diameter, slenderness ratio of these curves (L/D=8). Due to the pressure effect from the applied load with an applied electric current of (5v), the pore water pressure begins to rise until it reaches the highest position then it began to descend gradually and reached the lowest value of pore water pressure in the sixth month because the water drained from the soil due to the length of the granular column, which shortened the path of water drainage in addition to shedding electric current.

The second curve shows the pore water pressure when voltage increases (15V) for the electric current between the electrodes (anode and cathode) planted inside the granular columns in soft soil the curve shows a decrease in the pore water pressure from the previous voltage curve (5v), which means that when the applied voltage increases, the drainage of water from the soil increases faster in the same six-month period.

When the applied voltage was increased (30v) with the use of granular column length (8m) and diameter (1m) as in the third curve, which shows the relationship between the pore water pressure of soft soils in which the granular columns are embedded in a period of six months, the pore water pressure of soft clay soil treated with granular column and the electric current is small compared to the pore water pressure from previous voltage because the current is applied with a high voltage. Application of the potential between the anode and the cathode led to an increase in the concentration of negative ions from the positive because the surface of the clay particles is negative, which led to the drainage of water.

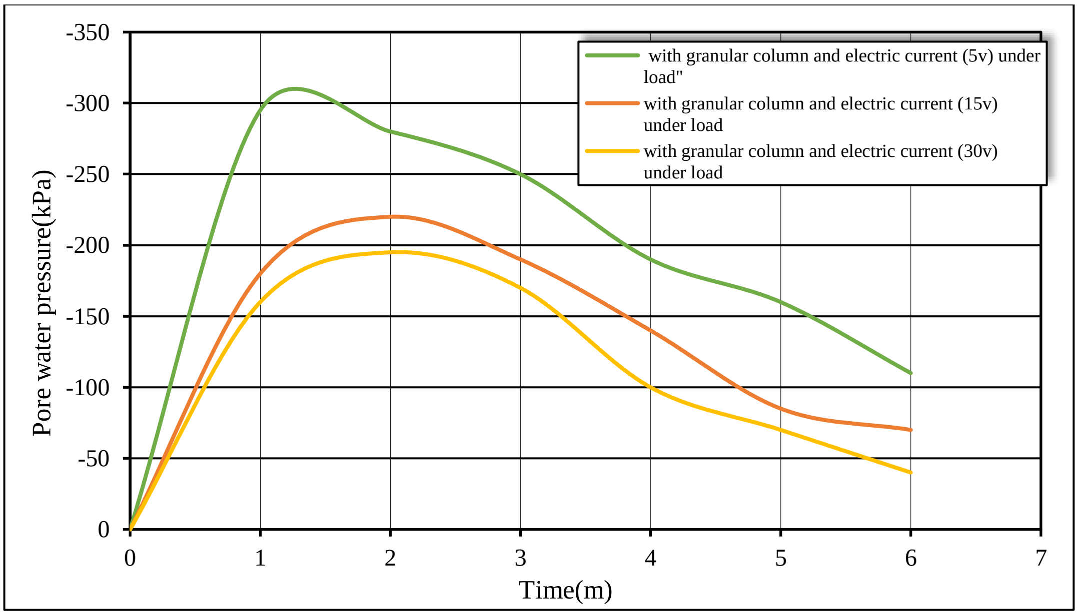
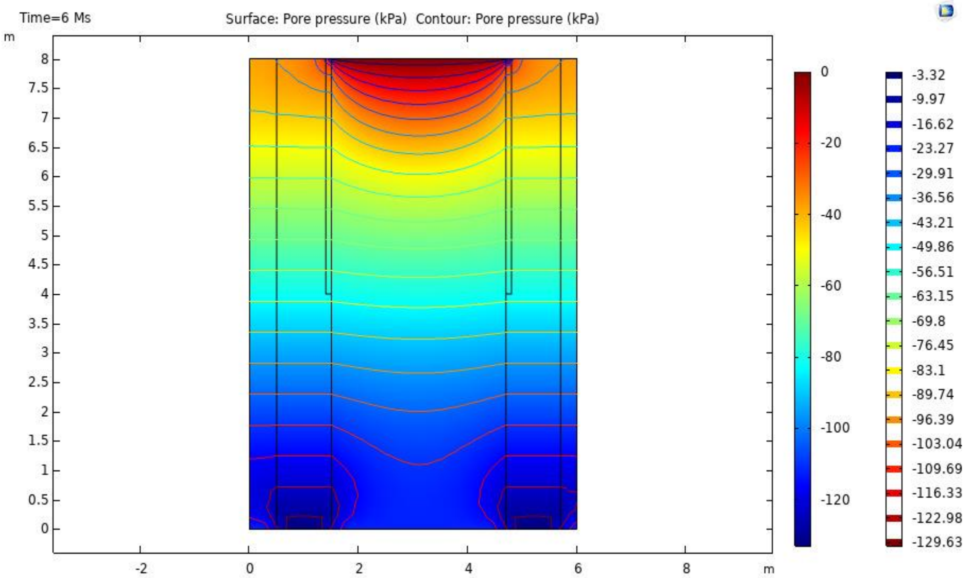
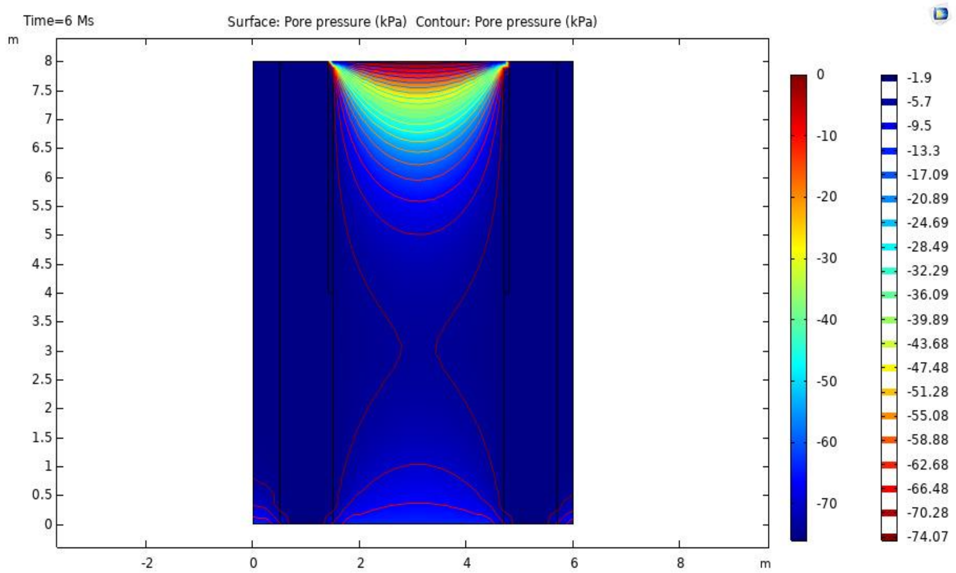


Figure 5. Time pore water pressure relationship of soft soil treated by granular column and electric current for (5,15, and 30v)

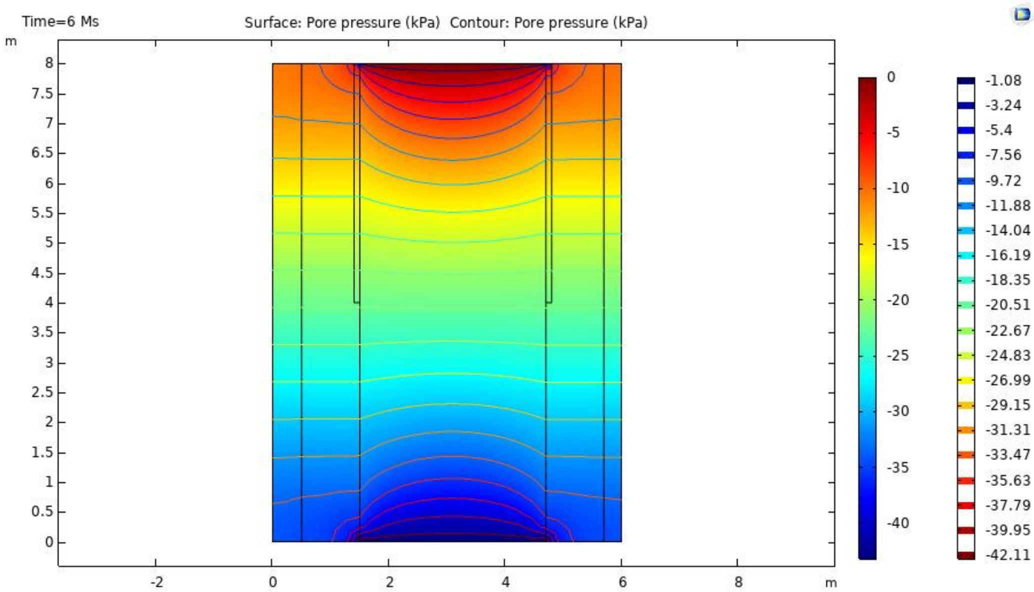
In Figure (6. a) the contour lines show the pore water pressure distribution in soft soils. When an electric current is applied (5v), the distances between the lines are few in the first two meters from the soil surface due to their influence by pressure from the applied load, in addition to shedding the electric current, which accelerates the exit of water from the soil then it expands and its value increases until it reaches the end of the soil due to the lack of its effect by pressure from the load imposed on it. Figure (6. b) the contour lines show the distribution of pore water pressure in soft soils when an electric current is applied by (15v). The increase in the applied voltage led to an increase in the pressure of the lines expressing the pressure of water molecules in the first two meters of the soil surface, in addition to the effect of the soil by the applied load, then the lines were less affected Contour in the depth of the remaining soil to the end. In Fig.(6.c) the contour lines show the distribution of pore water pressure in soft soil. When an electric current is applied by (30v) the lines expressing the pressure of water molecules are accumulated in the first meter of the soil surface, in addition to the influence of the soil by the applied load, then the effect of the contour lines in the remaining soil depth decreased to its end and the values of pore water pressure decreased, which means more drainage of water from the soil by increasing the applied voltage.



(a)



b)



c)

Figure 6. Relationship between pore water pressure with depth in six months for: (a)at five voltages, (b) at fifteen voltages, (c) at thirty voltages

Figure 7 shows the relationship between soil settlement and the time of six months for soft soil containing granular columns with an electric current of various voltages (5,15, and 30v). The first curve represents the soil settlement when a current of 5v is applied. The settlement increases gradually over time until it reaches the highest value (0.2m) in the sixth month, in order to drain the water from the soil pores due to the pressure from the applied load in addition to shedding the electric current. The second curve represents the soil settlement at (15v) The settlement increase over the previous curve with the increase in the applied voltage, as its value reaches (0.4m) in the sixth month. when a current is shed by (30v) the soil settlement increases slightly over the preceding curve and reaches its highest value in the sixth month (0.56m) the increase in voltage leads to an increase in the drainage of water from the soil, which was the reason for the increase in its settlement, but its effect is less when its value is increased than (25v).

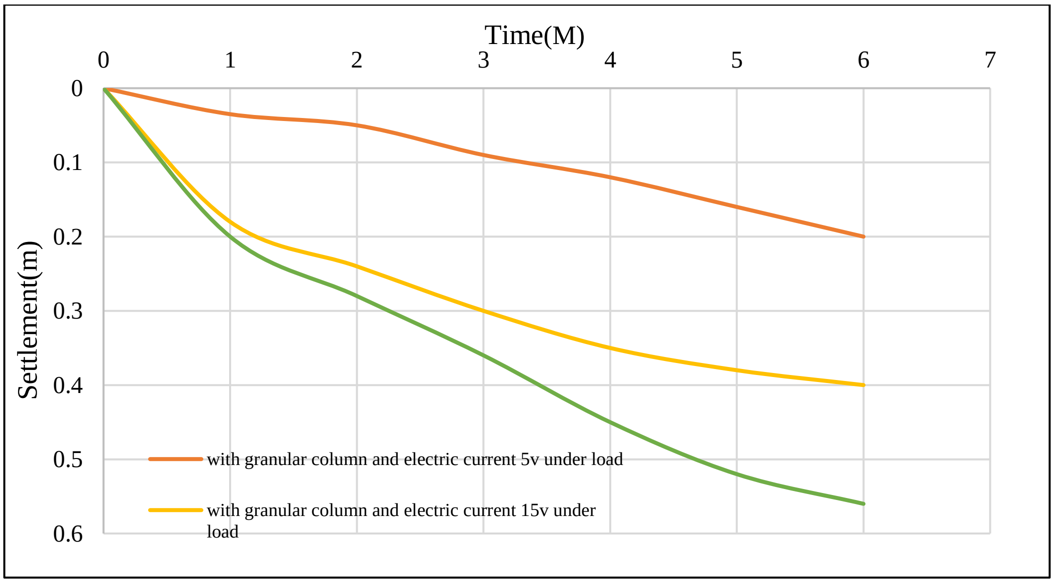


Figure 7. The relationship between time and settlement of soft soil with granular column and electric current of (5,15, and 30v)

To verify the program, Fig. 8 shows the results of pore water pressure obtained using the current soil model with a granular column without applying electric current with a time period of 1 to 1000 days and agrees with other solutions reasonably close to those of (Elsawy,2010) field tests of highway embankment constructed on soft soil improved by granular columns in Aswan, Egypt, and are consistent with the experimental solutions used in this study.

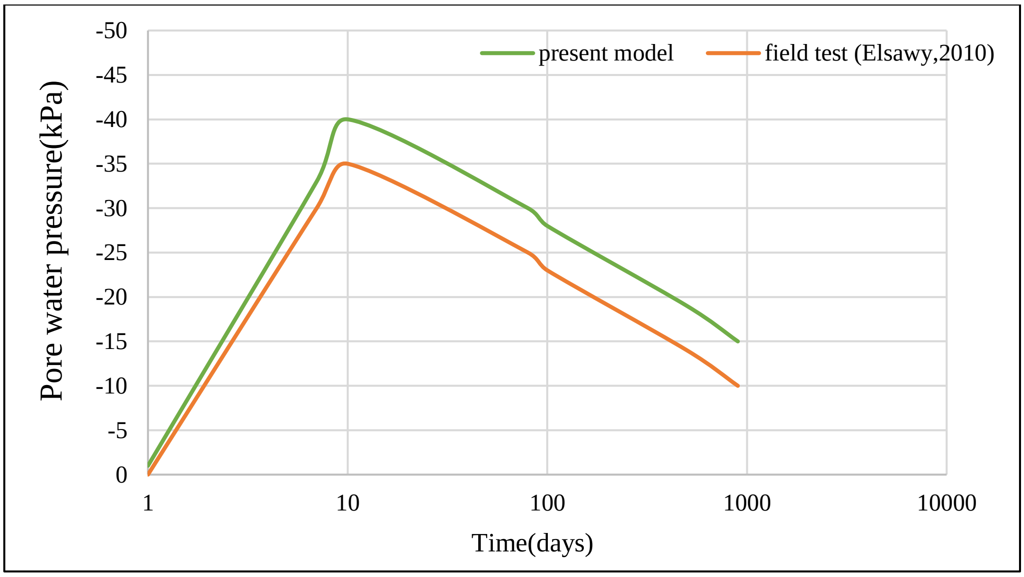


Figure 8. The pore water pressure of the present model and field test

4. Conclusions

The numerical model for the electro-osmosis treatment analysis of soft clay is summarized in brief, the model was used to simulate the pore water pressure of soft clay soil due to electro-osmosis technology, and based on what happened in the past, it can be collected that the soil and granular column responded to the electric current applied to them and improved after six months for disposal of the water in it, and the pressure of the water molecules in the soil decreased after the electric field between the anode and cathode was spilled at high voltages, The result found that:

1. When the electric current is applied with a voltage of (٥v) the pore water pressure in the soil increases in the first two months, reaching (300 kPa), and then begins to gradually decrease, reaching in the sixth month (120 kPa) mean water comes out of the soil slowly.
2. When the applied voltage increases by (15v) the pressure of the water molecules in the soil decrease in the first two months from the previous ratio of voltage, reaching (220 kPa), then it begins to gradually decrease and reaches the sixth month (70kPa), this means the increase in voltage led to a decrease in the pore water pressure to drain the water from the soil.
3. When the applied voltage increases more by (30v) the pore water pressure in the soil decreases in the first two months from the previous ratios of voltages, reaching (190kPa), then it begins to gradually decrease and reaches the sixth month (40kPa), which means the more the applied voltage increases, the more water is discharged from the soil.
4. The percentage of water leaving the soil when an electric current is applied (5-15v) was (64%) and when the applied voltage increased (15-30v) became (75%) which means the applied voltage increased, causing more water to be discharged from the soil.
5. The soil settlement increases with an increase in the applied voltage, as the

improvement percentage and the water exit from the soil (50%) at (5-15v) and (71%) at (15-30v).

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