The Potential of Soft Soil Improvement Through a Coupled Technique Between Electro Kinetic and Alkaline Activation of Soft Soil

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Abstract. Soil stabilization techniques have been in development for decades with different rates of success. Alkaline activation of soft soil is one of those techniques that has proved to deliver some of the best shear strength values with minor drawbacks in comparison with conventional soil stabilization methods. However, environmental considerations have not been taken into account, as major mineral glassy phase activators are poisoning alkaline solutions, such as sodium-, potassium-hydroxide, and sodium-, potassium-silicate, which poses serious hazards to man and environment. This paper addresses the ways of discarding the involvement of the aforementioned alkaline solutions in soft soil stabilization by investigating the potential of a coupled electro kinetic alkaline activation technique for soft soil strengthening, through which the provision of alkaline pH is governed by electro kinetic potential. Uncertainties in regard to the dissolution of aluminosilicate as well as the dominance of acidic front are challenges that need to be overcome.

Keywords: Soil stabilization, soft soil, electro kinetic.

1. Introduction
Sites that are considered abandoned due to their lack of bearing capacity have become a desired destination of contractors and governments all over the world. Their increased concern is related to the utilization of this given opportunity to launch huge projects on them [1]. However, clay soil poses problems to geotechnical engineers because of its complex nature. This derives from its low hydraulic conductivity, its plasticity, and therefore the time dependency of volume as well as pore water pressure change. Thus necessitating its treatment to modify its mentioned properties so as to stand firm constructions above it [2].

A common and significant approach applied is cement grouting to overcome the aforementioned problems by gluing the soil particles together mainly through chemical reactions. In terms of
mechanical strength, cement-based binders usually deliver noteworthy results. However, concerns have been recently raised due to the high CO2 emission estimated at 7% of the total anthropogenic CO2. In addition to producing a soil cement basic binder, it is necessary to seek for a specific aggregate, which rarely occurs. Therefore it appears necessary to come up with a substitute for cement that can be easily sourced and also features the same mechanical characteristics. Binders such as carbon fly ash is a waste material containing aluminosilicate, which not only fulfill all above mentioned conditions but also its economic costs are considered very low compared with cement grouting techniques [3].

2. Alkaline activation of Soft soil
Alkaline activation of soft soil is a relatively new scientific field, utilized for concrete stabilization where alkaline solutions such as sodium hydroxide, potassium hydroxide, and sodium silicate are introduced to wastes such as carbon fly ashes, metallurgical slags, and to metakaolinite in order to activate the mineral glassy phases of the last mentioned precursors. Thereafter the mixture is added to concrete to improve its stability [4].

The potential of introducing synthetic product of alkaline solution and source binders such as fly ash, metakaolinite, etc. to soft soil to improve its mechanical properties has been investigated by plenty of researchers [3,5,6,7,8]. Alkali solutions such as sodium-, potassium- hydroxide and sodium-, potassium-silicate are very essential for the gel hardening reaction. They supply OH ions used to attack the sialate-siloxo bonds for the liberation of alumino and silicate to form a large network. This further turns into a gel, gets rearranged and finally condensate by releasing the pore water to produce a hardener [9]. To allow for such synthetic product to form, highly alkaline conditions are necessary pH>11 [10]. The aforesaid alkali solutions pose serious hazards to humans and environment. Such dangerous solutions are highly exothermic, which means large amount of heat is released upon reacting with water and can lead to severe consequences such as poisoning, when not properly handled. Poisoning can occur in several ways, such as through touching, swallowing, and inhaling, which can cause lung inflammation, throat swelling, vomiting, skin burning and possible bleeding [11].

Therefore it is needful to develop a new technique that does not make use of alkaline solutions but instead utilizes a proper pH provider to attain the required PH levels. One of the well-known soil stabilization methods is electro kinetic soil stabilization. Its advantages over conventional methods are those of low expense, rapid achievement, wide scope of application and a site accessibility to maintain or fix any soil failure arising either after or before project is terminated [12].

3. Electro kinetic soil stabilization
The principles of EK stabilization method involve applying a low direct current or a low potential gradient to electrodes embedded in a low permeable soil, from which water is not to be drained readily. The migration of charged species across the soil involves several complex mechanisms such as electrolysis, electro-osmosis, electro-migration and electrophoresis. The technique can also be enhanced by the employment of suitable nontoxic chemical lime or cement solutions to the soil by introducing them at the appropriate electrode. The combined effect of these mechanisms with other geochemical reactions alters the chemical composition of the soil porous medium and thus physicochemical properties of the soil are modified [13].

The movement of fluid and solute through soil depends upon precipitation and dissolution reactions, which in turn hinge on pore fluid alkalinity as well as on the concentration of ions. During EK treatment, the soil electrochemistry is substantially changed. This can cause oxidation and reduction of the species, which are pH dependent reactions. The resistance of the soil to pH changes can affect the geochemical reactions fundamentally. The movement of charged species across the soil comprises 4 complex mechanisms, namely electrolysis, electro-osmosis, electrophoresis and electro-migration (Fig.1). The electric DDL at the charged surface of clay particles gives rise to the EK phenomena, which includes electrophoresis, electro-migration and electro-osmosis. These
electrochemical processes result in altering the hydrological physicochemical and engineering properties of the soils under electrical potential.

![Figure 1. Schematic diagram of various electrochemical processes under EK treatment technique after [14].](image)

Electrolysis reactions occur at the anode and cathode zones, resulting in oxidation & reduction respectively. \( \text{O}_2 \) and \( \text{H}^+ \) are generated at the anode (oxidation), while the electrical field employed induces \( \text{H}_2 \) and \( \text{OH}^- \) to be released at the cathode (reduction) as follows:

\[
\text{Anode: } 2\text{H}_2\text{O} - 4\text{e}^- \rightarrow \text{O}_2 + 4\text{H}^+ \tag{1}
\]

\[
\text{Cathode: } 2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^- \tag{2}
\]

Accordingly an acid front is formed in the vicinity of the anode and a base front dominates over the cathode zone. Both fronts move towards each other. The acid front moves faster than the base front due to the higher mobility of \( \text{H}^+ \) compared with that of \( \text{OH}^- \). As a result, the acid front governs the chemistry that occurs all across the specimen except in the vicinity of the cathode. Electro-osmosis is the migration of the pore fluid from the anode towards the cathode by means of an electric field. Electrophoresis is the migration of charged particles under electrical field in pore fluid to either the anode or the cathode depending upon its charge, while electro-migration is the movement of the ions or charged electrical species towards the appropriate electrode under an electrical potential difference. Species, which have no surface charges, are dragged along with the electro-osmosis stimulated water flow [14].

### 4. Utilization mechanism of electro kinetic phenomena in the alkaline activation of soft soil

It is claimed that the absence of alkaline solution, which is the main trigger for the pozzolanic reaction of synthetic geopolymer product, is compensated by electrical gradient, induced by electro kinetic process. In the cathode vicinity a high PH is expected to develop as more \( \text{OH}^- \) ions are produced and hindered by the electroomotic flow when electrical potential is employed. These \( \text{OH}^- \) ions are anticipated to attack the sialate-siloxo bonds for the liberation of alumino-silicate species to further form the geopolymer hardener. As mentioned above, the electro kinetic process results in dissolution and precipitation of several ion species, which are absorbed on the soil surface, generating a high pH.
Released Al ions can be utilized in the formation of the geopolymer product. The introduction of a specific chemical solution, such as calcium chloride and potassium chloride, at appropriate electrodes can also enhance and stimulate the electro kinetic alkaline activation of soft soil.

5. Challenges and limitations

Some challenges might be faced in regard with dissolution mechanism of aluminosilicate species as the former is dissolved between PH 11 and PH 14, depending upon the source material used. Even if these PH levels are obtained, it still remains uncertain, whether they can be maintained over long periods, given that availability of OH ions is dependent on several factors such as soil conductivity and electrical gradient. Therefore it is advisable to seek help in the chemistry to find out how aluminosilicate is otherwise dissolved. In addition it is known that H ions are as much as twice the OH ions and faster too. For this reason the dominance of acidic front across the specimen is likely to happen. Finally whether or not the hardener is obtainable by only involving alkaline water remain unknown before implementing trials. It is therefore strongly advised to direct the efforts towards overcoming these challenges before embarking on the electro kinetic activation of soft soil.

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