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Feasibility Study of Coupled Hydraulic and Electrophoretic Injecting colloidal silica in sand

M. A. Nozari , R. Ziaie Moayed

Department of Geotechnical Engineering, Faculty of Engineering, Imam Khomeini International University, Qazvin, Iran

ABSTRACT: Electro kinetic approach is a conventional method to improve soil characteristics. Dewatering, heavy metal remediation as well as injection stabilizers such as sodium silicate, colloidal silica and ionic solutions, especially in clayey and silty soil, which are sensitive to high pressure methods, are applicable via electro kinetic way. As a green product stabilizer, colloidal silica a dispersion of nano silica particles in water medium phase has been widely investigated by researchers. To quantify the effect of various factors such as solution electrochemical properties and electro kinetic injection conditions on stabilized soil and pore fluid, a suitable apparatus is necessary for laboratory tests. The apparatus should facilitate control and management of hydraulic and electro kinetic conditions. So, the main objective of the paper is to study the electro kinetic injection synced with hydraulic one into loose sand via appropriate instrument. An appropriate device has been designed and constructed and validated by feasibility tests. The trend of current intensity was compatible with previous works as well as uniaxial shear strength and shear wave velocity increase of soil. In conclusion, built apparatus could be useful for future studies.

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1- Introduction

Traditional ways of soil stabilization are usually not feasible for treating soil underneath existing structures because of the limited accessibility and the unpleasant level of noise and vibration. Passive remediation methods are some process of ground improvement in which the soil layer will not experience the settlement and heaving by stabilizer permeation [1]. To aim a safe stabilization, a suitable grout material is a major concern as well as the method of grouting. Low hydraulic injection and electro kinetic grouting are two types of passive methods. electrophoretic injection, one of the main phenomena of electro kinetic injection, is the movement of charged particles such as colloids under direct current field. Owing to the fact that there is no fluid regime in electrophoretic injection, this method could be useful to achieve passive method in fine grained soil [2].

Colloidal silica, an aqueous dispersion of silica nanoparticles, is broadly used in ground improvement investigations because of its appropriate properties such as low viscosity, durability and adjustable gelling modulus [3]. Moreover, the charged nano particles in colloidal silica, depended on the electrochemical properties of soil and pore fluid, could be translated by electrophoretic injection.

However, the increase of the shear strength of loose silty and clean sand has been investigated before [1, 2, 4, 5], but the effect of synced grouting via hydraulic and electrophoretic means were not obvious up to now. Aiming to this goal, this paper has presented the design and fabrication an apparatus to investigate simultaneous hydraulic and electrophoretic injection of colloidal silica in fine grained sand. After the injection, stabilized specimens have been tested to evaluate how the synced injection influence the degree of improvement by uniaxial strength and shear wave velocity measurement.

Corresponding Author, Email: ziaie@eng.ikiu.ac.ir

2- Methodology

A simplified device has been designed to inject colloidal silica under controlled hydraulic gradient. Additionally, two graphite disks were placed at the end space of compartments which have three valves to exit produced gas because of electrolysis and outgoing fluid. Overflow method was applied to introduce constant hydraulic head. Two split molds were used to assure safe extrusion soil specimen after grouting. Figure 1 shows a schematic array and implementation of apparatus.

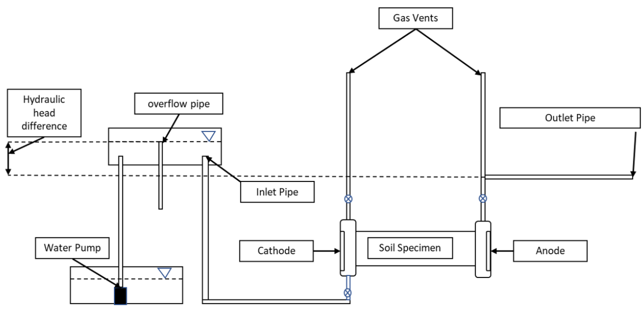

Figure 1. Schematic design and assembly of apparatus elements

The soil specimens at relative density of 30% were prepared using under compaction method proposed by Ladd in 1977 [6]. Particle size distribution curve of Firoozkooh sand, a poorly graded sand, Number 161 is depicted in Figure 2.

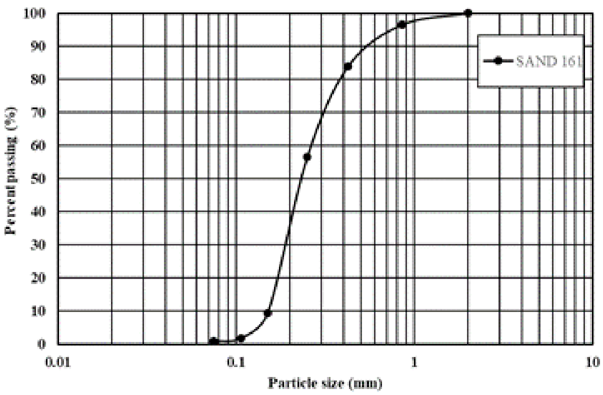

Figure 2. Particle size distribution of Firoozkooh sand Number 161

Following the soil saturation, colloidal silica grout (30%wt) with electrophoretic mobility of -3.3 cm^2 /v.s and average particle diameter of 10 nanometers injected into specimens different ways. The first specimen (EP-H) was simultaneously injected. The hydraulic regime was under gradient of 0.067 for 4 hours so that the amount of colloidal silica near to 250 gr was injected to specimen. This value is about the half of the pore volume. So, if at the end of the specimen any gelation were observed, it could be as a result of electrophoretic injection. The electrophoretic injection at EP-H test is under 60 v and electric field of 4 v/cm. A suspension of colloidal silica was used with 30% silica weight at pH=9 and zero ionic strength. Electrical field was applied by the power supply (GW-Instek, South Korea) and electrical current was measured. The second test (H) was hydraulically injected under the hydraulic gradient of 0.067 until the exited flow volume equals to the corresponding amount in EP-H test. At the third injection (EP), only the electrophoretic injection was conducted for 24 hours similar to EP-H, however the gas in compartment did not exhausted. the fourth type of the tests (EP-EL) was started similar to EP-EL for a day and continued by electrolysis for two days. Electrolysis was applied to compare the effect of pH due to the producing H+ near to the anodes. All the specimens were cured for 28 days without any humidity exchange. Then, shear wave velocity and uniaxial strength of specimens were measured.

3- Results and Discussion

Four kinds of injection tests were conducted. Change in current intensity across the whole of the specimen is depicted in Figure 3. As it is clear from Figure 3, there is a drop trend that is can be originated from decrease in effective area of anode and cathode due to gas production. After 28 days, clearly, the half part of the specimen near to anode had significant cementation.

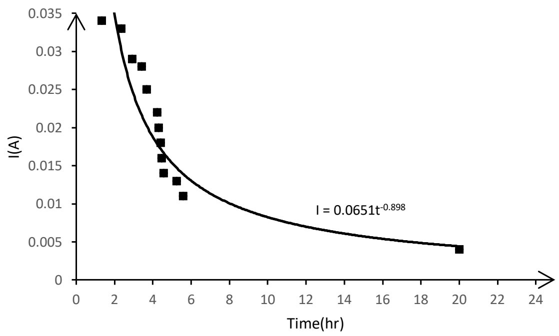

Figure 3. Variation of the current intensity

The variation of the current intensity of EP-H was in accordance with the introduced colloidal silica mass as it is obviously showed in Figure 4. There is an increase in intensity while the colloidal silica mass rises by the time. It could be concluded that more colloid mass leads to more intensity. After 28 days, EP-H specimen could not be loaded because of the weak cementation as well as H specimen which had equal introduced amount of the colloidal silica. The main reason could be interpreted as the electrochemical condition of specimen has been governed by the hydraulic flow so that the pH of the exited fluid, measured after he injection, was equal to the initial value of 9. So, the gelation has postponed and 28 days curing time was not enough to cementation.

In EP-El tests, after the EP step, electrolysis for 48 hours produced a large amount of the H+ in both compartments. Decrease in pH caused significant gelation and considerable silica gel was in compartments after 28 days. Shear wave velocity of samples was measured via Bender element test as enlisted in Table 1.

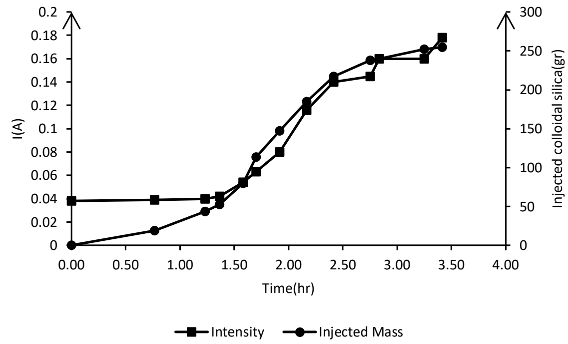

Figure 4. Variation of the current intensity and injected colloidal silica mass in EP-H test

Table 1. Shear wave velocity of grouted and clean sand

Specimen Label	Shear wave velocity (m/s)
Clean sand	84
EP	312
EP-EL	396
EP-H	204
H	287

It is clear that EP and EP-El samples had larger value of Shear wave velocity. The samples with hydraulic flow had weaker cementation so that the increase in Shear wave velocity are lower than the other ones. As a main conclusion, it could be stated that electrophoretic injection without hydraulic flow resulted in cementation at the vicinity of the anode. So, the nano particles have arrived to the end part of the soil. On the other hand, one of the main factors which accelerate the gelation was electrolysis and decrease in pH value. In H and EP-H tests, hydraulic flow governed the electrochemical condition and did not permit the gelation occurred at 28 days. The samples EP and EP-EL were loaded under unconfined condition to measure the acquired value of cohesion. Figure 5 shows stress-strain curve for both samples.

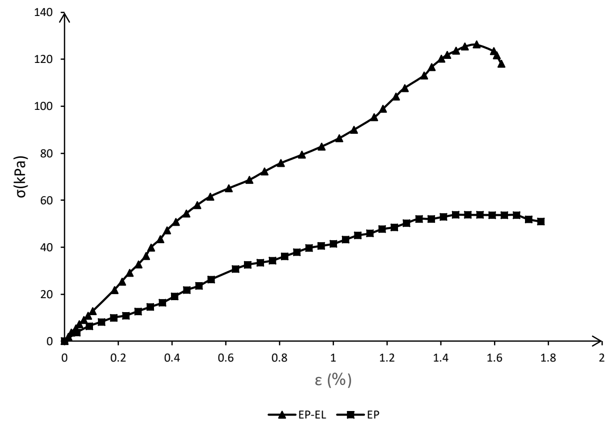

Figure 5. Unconfined compression tests of EP and EP-EL samples after 28 days curing day

The peak stress of the EP sample was 38 kPa although the corresponding value for the EP-EL sample was 126 kPa. The significant difference has risen from the electrolysis step in EP-EL tests.

4- Conclusions

From the research that has been carried out, it could be concluded that the simplified design of an apparatus and the assembly of different elements which used to evaluate the synced injection of colloidal silica in sand media via hydraulic method as well as electrophoretic one, was valuable. The results have clearly shown that electrophoretic injection of colloidal silica with suitable initial properties such as pH and electrophoretic mobility could be useful to stabilize the loose sand. On the other hand, the influence of the electrolysis throughout the injection accelerate the gelation and cementation opposed to the hydraulic regime.

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