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An Effect of Sodium Polyacrylate on Sandy Soil Parameters and Its Use in Soil Improvement

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Abstract **-** Superabsorbent polymers, which swell into gel form when in contact with a liquid, can absorb hundreds of times their own weight in water. They have different application areas such as agriculture, drug delivery, cleaning, and cosmetics. In this study, the effect of sodium polyacrylate on the basic sandy soil parameters and its use in soil improvement applications against liquefaction were evaluated as a new approach. Sodium polyacrylate was used by mixing with cement at an optimum rate around 25.00% by weight, since gel form releases back water if exposed to load. To examine the effect of sodium polyacrylate-cement gel on the mechanical properties of sandy soil, shear box and permeability tests were performed by mixing the gel with the soil in four different ratios. In addition, the changes that occur as a result of the improvement were investigated in following cases; horizontal layer, vertical layer, mixed with soil and column application with different spacings. Due to the increase in gel content, the permeability values decreased and the shear strength increased more than two times. In the experiments conducted with the shaking table, the soils were exposed to dynamic effects after the application of the mixture within the purpose of elimination the liquefaction problem. It was concluded that the observed settlements on the soil surface decreased between 25.90% and 92.60% thanks to the improvement applications. In addition, a reduction level up to 39.00% occurred in the pore water pressure. Finally, the usability of sodium polyacrylate-cement mixture is proven to enhance the properties of sandy soil.

Keywords**:** Sodium polyacrylate, soil improvement, soil mechanics, shear strength, shaking table, settlement.

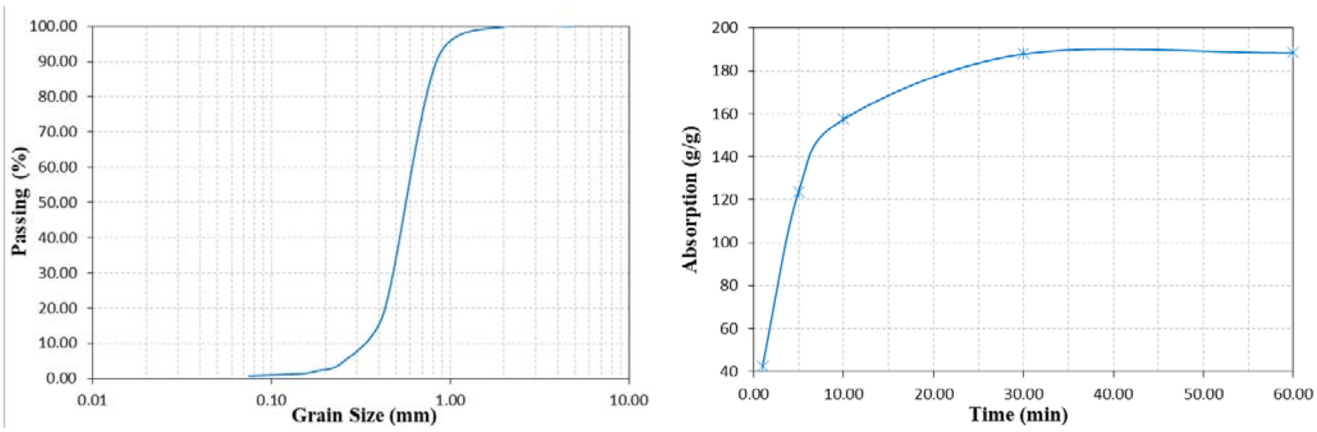
1. Introduction

Sodium polyacrylate (SPA) is a super absorbent polymer that can absorb huge amounts of water in its structure. SPA, which is a white crystalline or powder-like form, immediately swells and turns into a gel state when in contact with water. If there is enough sodium polyacrylate in the environment, the crystalline particles absorb water and turn into large gel spheres [1]. It can absorb 100-200 times its own weight in water, depending on degree of purity, particle size and crosslinking rate. When it interacts with water, the SPA expands as the water is absorbed and held by the SPA molecules, thus acting like an extremely strong sponge [2]. However, the ions in the water reduce the water absorption capacity [3]-[4]. Due to their high-water absorption capacity, superabsorbent polymers have a wide range of usage areas such as hygiene products [5], agriculture [6]-[7], ice bags, cables, water-absorbent pads, wastewater treatment [8], internal curing of concrete [9]-[10], oil well cements [11]-[12].

The objective of this study is to use SPA to improve the mechanical properties of the soil, reduce its saturation and thus reduce the risk of liquefaction. Although various polymer additives [13]-[14] are used to improve soil properties, there is a lack of studies about the use for superabsorbent polymers in soil improvement studies directly. Its unique water absorption ability around 125 folded level makes the SPA a good alternative to improve soil properties. In addition, it does not have any negative effects on human health and does not contaminate the soil and the environment [15]. Although the main problem of sodium polyacrylate is that absorbed water is releases depending on time, some of the released water can be re-absorbed over time according to Sohn and Kim [16]. In order to solve the decreasing potential in water absorption capacity under load [15], it was decided to use SPA by mixing it with cement at the optimum sealing limit value within this study. Thus, it was aimed to ensure that the water released by the SPA is absorbed by the cement. As a result of the experiments carried out with SPA-cement-water mixtures at different ratios, the optimum limit value of sealing was determined as 25.00% of the dry SPA weight. This cement ratio corresponds to 0.2% of the weight of the SPA in gel form, approximately. In the study, the effect of the SPA addition on the permeability and shear strength parameters of the sandy soil was investigated. Moreover, the improvement levels in terms of surface settlement and pore water pressure values were examined as a result of applying the SPA in various application cases.

2. Material and Method

All experimental studies were conducted using poorly graded silica sand with a specific gravity of 2.45, maximum and minimum dry densities of 1.71 and 1.45, respectively. The grain size distribution of silica sand is given in Fig. 1a. The tea bag method was used to investigate the absorption capacity of sodium polyacrylate used in the experiments. It is the most traditional and frequently used methods for determining the absorption capacity of superabsorbent polymers [15]-[17]. After, 0.1g SPA was placed in a tea-bag and immersed in water, it was removed from the water at certain times (1, 5, 10, 30, 60 min) and the excess water was gently wiped with a dry cloth and weighed. The short-term water absorption capacity of the SPA was determined as 125 g/g (Fig. 1b). The same value was also confirmed by viscosity tests [2] since viscosity of the gel has dropped significantly after 125 g/g water absorption capacity, and it has behaved like water.



a b

Fig. 1: a: Grain size distribution curve of silica sand, b: Water absorption capacity of SPA

In order to evaluate the effects of sodium polyacrylate-cement addition on shear strength parameters and hydraulic conductivity of the soil, the shear box and the constant head permeability tests were carried out in accordance with related standards [18]-[19]. Twelve permeability and twelve shear box tests were conducted by adding SPA-cement gel at 4 different rates (5.00%, 10.00%, 15.00 and 20.00%) in addition to reference experiments on clean sand. Then, shaking table tests were performed to evaluate the usability of the SPA in soil improvement works. The experimental setup consists of, a 35.70 cm x 33.60 cm plexiglass cell, a constant head water tank and pore water pressure gauges with the capacity of 200 kPa (Fig. 2). Inner surfaces of cell were covered by 2 layers of styrofoam with grease at midpart to eliminate the reflection of dynamic waves. Silica sand was poured into the cell via dry pluviation technique with the most susceptible relative density (D_r = 47.80%) against shaking. Afterward, the SPA-cement mixture was applied in 4 different ways as horizontal application, vertical application, complete mixing and column application. After the completion of full saturation process, soil cell was subjected to uniaxial shaking table test with 4.0 Hz frequency and 100 cycles. The changes in settlement and pore water pressure values were recorded by dynamic data acquisition system from steel plate placed at top level as a foundation and pore water pressure gauges, respectively.

Dry SPA-cement mixture was laid at two different depth from surface as 3.00 cm and 15.00 cm, which are positioned at upper and lower parts of gauges, with a 5.00 mm and a 10.00 mm thickness in the horizontal layer applications. In the vertical layer application, 0.25%, 0.50%, 1.00% and 2.50% SPA-cement mixture was mixed with the soil and poured at the height of the soil along the 10.00 mm wide area within 20.00 cm x 20.00 cm boundaries. In the column application, 10.00% SPA-cement containing sand was injected into the silica sand according to 3 × 3 arrangement. The column diameter was kept constant as 1.00 cm and the distance between columns was taken as 3, 4, and 5 folded values of column diameter from center-to-center. In the mixing application, the SPA-cement mixture was completely mixed with sand at the rates of 0.05%, 0.10%, 0.15% and 0.20% and the resulting mixture was placed in the plexiglass cell at the desired density.

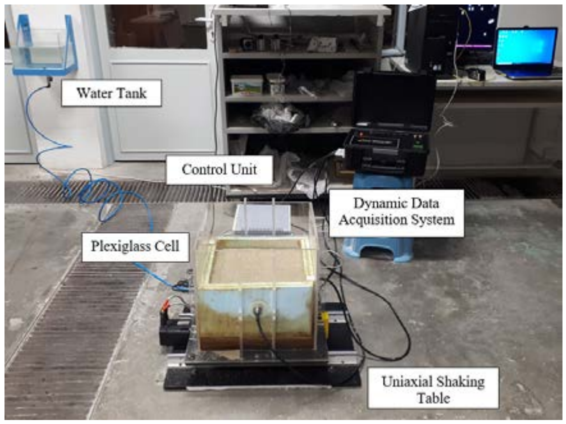


Fig. 2: Experimental setup [20]

3. Results

The changes in shear strength parameters and hydraulic conductivity values depending on the amount of SPA-cement gel are given in Fig. 3. It was observed that there was an increase between 2.00 and 2.40 times in the maximum shear stress value in the case of SPA mixture addition. A reference internal friction angle value increased by approximately 66.00% and 75.00% at 15% and 20% gel content respectively, while their positive trends on shear strength are similar. Although the cohesion value of the reference specimens sand increased with the SPA mixture addition, the maximum increment level occurred at 5% gel content.

The saturated hydraulic conductivity of sandy soil was significantly reduced with the addition of sodium polyacrylate according to Zhuang [6]. The results of constant head permeability experiments confirmed this approach (without only 20% gel amount), even if there is no obvious reduction as noted. This is attributed to the excessive amount of SPA causes large voids in the soil and produces a more porous structure. Shortly, the addition of the SPA-cement mixture decreased the permeability and increased the internal friction angle and cohesion of the sandy soil.

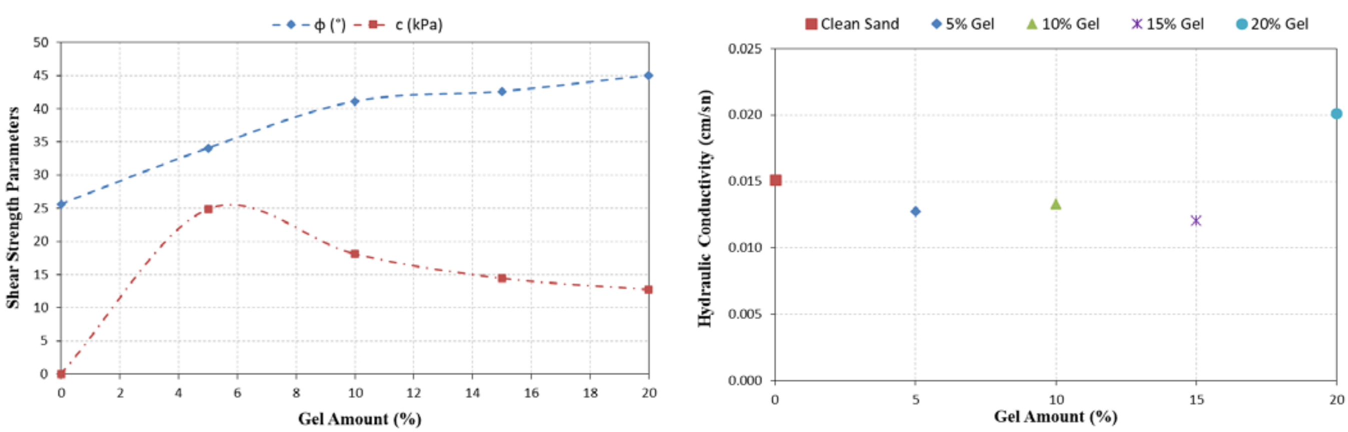


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Fig. 3. a: Shear strength parameters, and b: Hydraulic conductivity depending on gel amount

In order to evaluate the usability of the SPA-cement mixture in soil improvement works, a total of 15 improvement studies were carried out with 4 different applications. Among the definitions used for test samples, 'H' indicates layer application, 'VL' vertical layer application, 'MA' mixing application and 'C' column application. While '5' and indicate the thickness of dry mixture within horizontal layer application, 'U' and 'L' letters denote the upper and lower locations of the pore water pressure gauges respectively. The numerical values given after the abbreviation indicate the mixture amount for vertical layer and mixture application. The expression "D" is used to define distance between improvement columns. The obtained average settlement values are given in Fig. 4. Although same settlement level is observed in the C5D application with respect to reference one, in the remaining cases the amount of settlement was considerably reduced due to the addition of the SPA-cement mixture out of HU5 experiment.

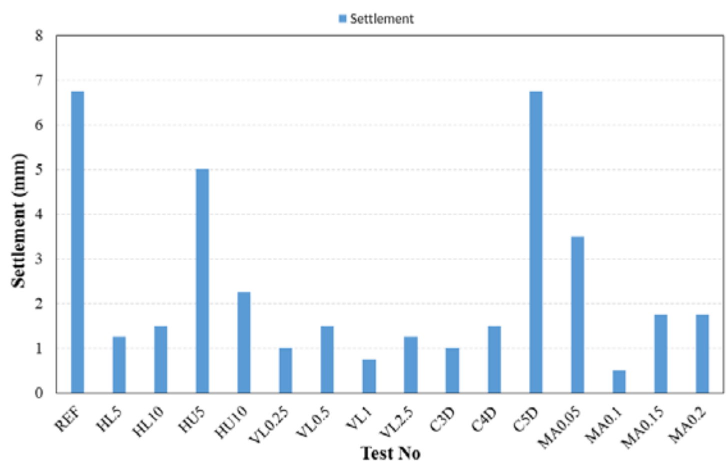

Fig. 4: The average values of surface settlement after shaking

The changes in average pore water pressure values are given in Fig. 5. Sandy soil without improvement has 3.95 kPa and -3.03 kPa pore water pressure depends on direction after shaking procedure as a reference value. The maximum level of damping occurred in C4D application in positive direction up to 2.40 kPa, while MA0.05 case has a minimum pore water pressure around 1.02 kPa in negative sign. The most effective column spacing was determined as 4 folded value of column diameter. According to the test results, soil improvement with SPA presented a unique behaviour due to application method in terms of dissipated pore water pressure in addition to serious level of surface settlement reduction.

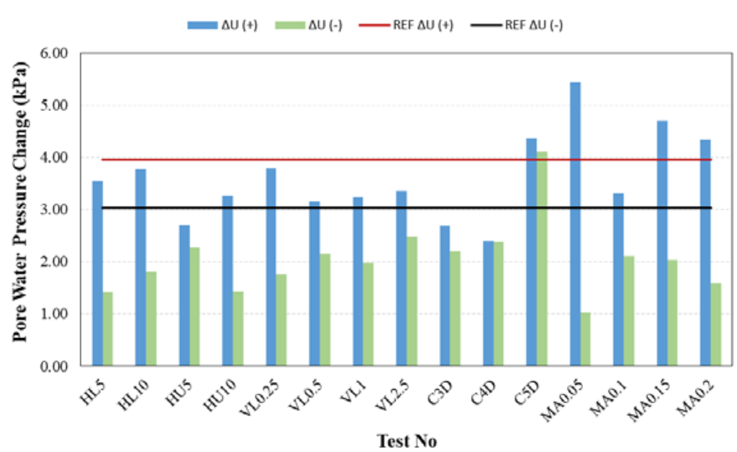

Fig. 5: The change in pore water pressure values due to type of used improvement application

4. Conclusion

In the study, the effect of sodium polyacrylate-cement mixture on various parameters of sandy soil and its usability in in soil improvement applications were evaluated. In this context, shear box and permeability tests were carried out by adding adding 5.00%, 10.00%, 15.00% and 20.00% SPA-cement gel to silica sand and soil improvement tests were performed in in different application methods. The results obtained from the experimental research are listed below.

- The cohesion value of silica sand increased by 24.87 kPa in the case of 5.00% SPA gel addition, while the internal friction angle increased by 75.76% in the case of 20.00% gel addition. Moreover, there was an increase in the maximum shear strength between 105% and 144% kPa compared to the reference case.
- Although the hydraulic permeability decreased from 5.00% to 15.00% gel contents up to 20.00% level, it increased about 33.00% at 20.00% gel content. If the amount of gel added to the soil is above a certain amount, the excess amount of SPA on the soil causes a more porous structure.
- The amount of settlement decreased by 25.90% in the HU5 application as the least value and decreased by 92.60% in the MA0.1 application as the most rate. On the other hand, the complete mixing operation causes an increase in excess pore water pressure and therefore is not a suitable application method.
- In C4D application, which is the most effective situation for improvement works, the settlement and pore water pressure values decreased around 77.8% and 39%, respectively. Therefore, the application spacing of column case is determined as 4 folded value of diameter.
- The results of the study proved that the SPA-cement mixture can be used for enhancing the properties of inappropriate sandy soil in terms of shear strength and permeability as well as the reduction of settlement and excess pore water pressure caused by the dynamic effect.

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