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THE EFFECT OF THE CHEMICAL GROUTING ON LIQUEFACTION POTENTIAL OF FINE SAND

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ABSTRACT

Grouting is a ground treatment method used for the remediation of the liquefaction. Cement based grouting is known as the most popular method of grouting. However, in the case of fine and medium sand, using of cement grout is difficult. In these cases, chemical grouting can be utilized as an alternative method. Sodium silicate is used more than other chemical grouts in fine sand.

In this study, sodium silicate was grouted with different degree of concentrations for remediation of liquefaction. Clean sand and grouted sand with different void ratios were tested using cyclic triaxial apparatus. The grout was injected into dry sand with different void ratios. The cylindrical Specimens were 50 mm in diameter. Specimens were cured in humid condition for 7 days. The strain versus time and pore pressure versus time, during cyclic loading were investigated. It was observed that use of sodium silicate grout will decrease the potential of liquefaction significantly. The rate of excess pore pressure generation, the formability and stiffness of soil specimens are strongly affected by changes in concentration of sodium silicate.

Keywords: chemical grouting, liquefaction, sand, triaxial test

INTRODUCTION

Soil liquefaction results in ground failures in forms of sand boil, differential settlement, flow slide, lateral spreading, and loss of bearing capacity beneath buildings During strong earthquakes.

The risk of liquefaction and associated ground deformation can be reduced by various ground-improvement methods including densification, solidification (e.g., grouting). For large, open and undeveloped sites, the easiest and cheapest methods for densification are by “traditional” procedures such as deep dynamic compaction, explosive compaction, or vibrocompaction. At constrained or developed sites, ground improvement by densification may not be possible due to the presence of structures sensitive to deformation or vibration.

Grouting is also considered a highly reliable remediation against liquefaction. It prevents soil particle movement and provides cohesive strength. Fine sandy soils are not normally considered groutable using cement-based grouts. In these cases, chemical grouting can be utilized as an alternative method. Sodium silicate is used more than other chemical grouts in fine sand. Sodium silicate grout uniformly permeates and makes a massive structure.

In this paper, series of cyclic and monotonic triaxial tests were done to assessment of sodium silicate grouting effect on liquefaction potential and cyclic behavior of loose sand. To obtain the specimen grouting was done in a plexiglas cylindrical moulds of 50 mm diameter and 500 mm height. then specimens were trimmed and cyclic and monotonic triaxial test were conducted.   .

MATERIAL

Two types of sand were used in this study. Firouzkooh No.131 and No.161 sand were used. Firouzkooh No.131 is artificially siliceous sand with very strong, angular grains and poorly graded and Firouzkooh No.161 is artificially siliceous sand too but its particles is smaller than No.131. The index properties of Firouzkooh sand No.131 and No.161 are presented in table 1 and 2. A gradation curve of Firouzkooh No.131and No.161 sands and the gradation range of most liquefiable sands are shown in fig.1.

The sodium silicate grout composed of sodium silicate (Merck), water and a hardener (HM40-5). The sodium silicate identification is: $Na2O$ 5%-8.5%, $SiO2$ 25.5-28.5%, density (at 21 °C) 1.296-1.396 gr/mL. The molecular ratio (Rp ¼ $SiO2/Na2O$) of grout was 3.2. The grout solution basically had a composition (based on weight) of 45% sodium silicate, 45% water and 10% hardener. The setting time of the grout was 50 min at an air temperature of 24 °C.

Table 1. Index properties for Firouzkooh No.161 Sand

USCS classification symbol	SP
D_{60} (mm)	0.28
D_{50} (mm)	0.26
D_{30} (mm)	0.20
D_{10} (mm)	0.16
Coefficient of uniformity, C_u	1.75
Coefficient of curvature, C_c	0.89
Specific gravity, G_s	2.65
Minimum index void ratio, e_{min}	0.548
Maximum index void ratio, e_{max}	0.832

$C_u= D_{60}/D_{10}$, $C_c=(D_{30})^2/(D_{10}\ D_{60})$ where D_{10} is the grain size that corresponds to 10% passing, D_{30} is the grain size that corresponds to 30% passing, D_{60} is the grain size that corresponds to 60% passing.

Table 2. Index properties for Firouzkooh No.131 Sand

USCS classification symbol	SP
D_{60} (mm)	0.56
D_{50} (mm)	0.50
D_{30} (mm)	0.41
D_{10} (mm)	0.32
Coefficient of uniformity, C_u	1.75
Coefficient of curvature, C_c	0.94
Specific gravity, G_s	2.65
Minimum index density (kg/m^3)	1377
Minimum index void ratio, e_{min}	0.629
Maximum index density (kg/m^3)	1626
Maximum index void ratio, e_{max}	0.924

$C_u= D_{60}/D_{10}$, $C_c=(D_{30})^2/(D_{10}\ D_{60})$ where D_{10} is the grain size that corresponds to 10% passing, D_{30} is the grain size that corresponds to 30% passing, D_{60} is the grain size that corresponds to 60% passing.

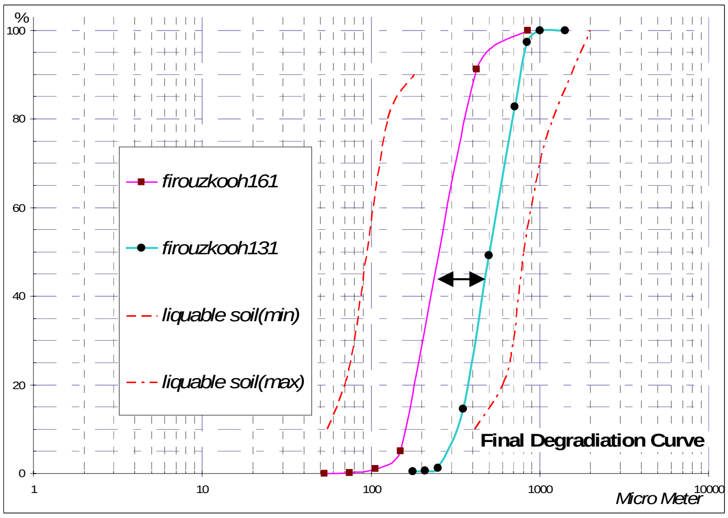

Figure 1. Grain size distribution for Firouzkooh No.131 and No.161 sand

Preparation of grouted sand

The preparation of the grouted sands in the laboratory is similar to the systematic procedure inspired by previously published injection devices (Zebovitz et al. 1989; Benhamou 1994; Schwarz and Krizek 1994; Tailliez 1998). A detailed description of the procedure can be found in Dano and Derache (2001). Briefly, the sand was placed with a zero fall height in a transparent and rigid cylindrical mould made of two segment of Plexiglas. The diameter of the tube was 50 mm, and its height was 500 mm. As the inner tube was being pulled up, as illustrated in Fig. 2, a few simultaneous hammer strokes on the Plexiglas mould compacted the soil. This method induced a satisfactory homogeneity for the soil. This procedure was also found to be repeatable for high relative densities of the granular skeleton.

The relative density of the samples subsequently tested was always about 45%. After the column was completely filled, the column was saturated with water. A fixed volume of grout equal to 1.2 times the initial volume of voids of the granular skeleton injected from the base to the top of the column at a constant volumetric flow rate of 3 cm3/s. The Grout permeation occurred without any significant pressure rise. Gradually the grout completely filled the inter-granular voids without visible fabric change of the granular skeleton. Three concentration of sodium silicate were used for injection. The lowest concentration, the medium concentration and the highest concentration (H-40-80), (H-40-60), (H-40-40) are respectively. Columns were kept in a humidity and temperature-controlled room for a period of 7 days. After this period, the mechanical properties of grouted samples became constant. Four samples with a height to-diameter ratio equal to 2 were cut from each column. Their faces were made parallel and smooth by straightening.

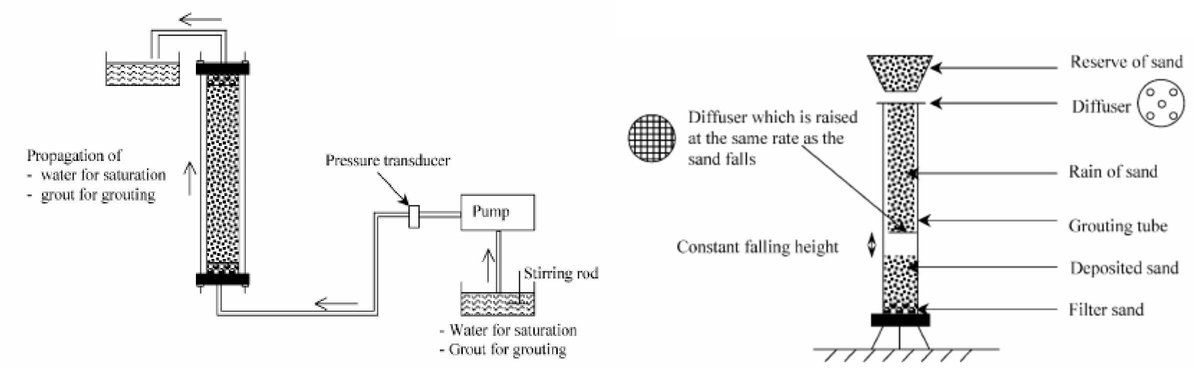

Figure 2. Laboratory preparation of grouted sands

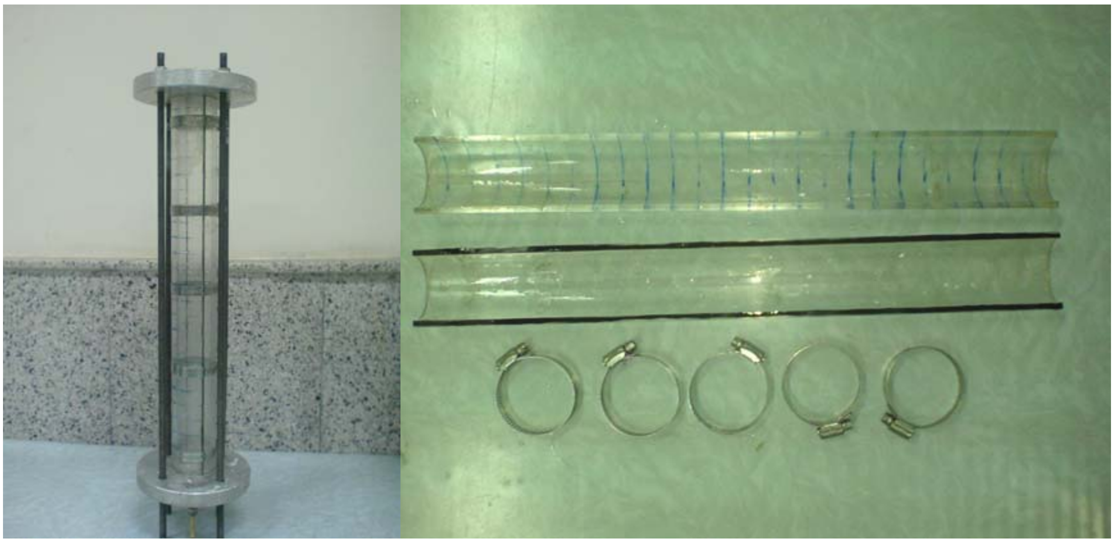

Figure 3. Mould used for preparation of samples

Testing

Monotonic triaxial tests

Although many studies have pointed out that the linear failure envelope, described by a friction angle and an intercept as cohesion, does not exactly represent the actual failure envelope of soils and rocks (Bishop 1966; Baligh 1976), these parameters remain widely used in current geotechnical design. They can be determined by means of conventional consolidated–undrained triaxial tests which were carried out on saturated uncemented sands (with B values always greater than 96%) and on grouted sands prepared in the laboratory. The axial strain rate was 1.5 %/min. Confining pressures were 0.1 and 0.2 MPa. The height to diameter ratio of the samples was close to 2. No lubrication was applied to the end platens. The results are presented in terms of deviator stress q versus axial strain. The axial strain was calculated from the sample shortening measured on an external micrometer, which induces an experimental uncertainty due to bedding and compliance errors. A load cell was used to determine the axial stress. Pore pressure was measured. Tests were done in CU condition. Effective stresses were obtained by measurement of pore pressure.

Cyclic triaxial tests

The cyclic tests were run in general accordance with ASTM D5311 standard test method for load controlled cyclic triaxial strength of soil. The tests were performed under undrained conditions (υ=0.5) for a confining stress of 0.1 MPa. Certain modifications to the test procedure were required because of the special properties of the treated sand. The pore pressure response and the axial strain during cyclic loading were measured to quantify the results of the treated soils. The equipment used for the cyclic triaxial testing was an automated triaxial testing system. The loading is controlled using closed-loop feedback systems capable of stress or strain controlled testing.

Table3. Parameters that considered in the tests

Soil type	Grout concentration	e (void ratio) (before grouting)	Typr of triaxial test
Firouzkooh No.161	Clean sand	0.7	cycl/mono*
Firouzkooh No.161	H-40-40	0.7	cycl/mono
Firouzkooh No.161	H-40-60	0.7	cycl/mono
Firouzkooh No.161	H-40-80	0.7	cycl/mono
Firouzkooh No.131	Clean sand	0.8	cycl/mono
Firouzkooh No.131	H-40-40	0.8	mono
Firouzkooh No.131	H-40-60	0.8	mono
Firouzkooh No.131	H-40-80	0.8	mono

*cycl=cyclic triaxial test, mono=monotonic triaxial test

Results and discussion

Cyclic triaxial testing results

Cyclic triaxial tests were conducted on Firouzkooh No.131 and Firouzkooh No.161 sand samples treated with sodium silicate grout to investigate the influence of sodium silicate grout on the deformation properties and pore pressure of fine sand under cyclic loading. Distinctly different deformation properties were observed between grouted and ungrouted samples.

Untreated samples developed very little axial strain after a few cycles of loading and prior to the onset of liquefaction. However, once liquefaction was triggered, large strains occurred rapidly and the samples collapsed within a few additional cycles. In contrast, grouted sand samples experienced very little strain during cyclic loading. What strain accumulated did so uniformly throughout loading and the samples remained intact after cyclic loading.

In general, samples stabilized with higher concentrations of sodium silicate experienced less strain during cyclic loading than those stabilized with lower concentrations. When tested at a CSR of 0.50, samples with 25% concentration of sodium silicate showed very little deformation during more than 1000 cycles of loading (for better viewing first 150 cycles were plotted). The cyclic deformation behaviour of grouted sand with 25% and CSR= 0.50 is shown in Fig.5. It means if the concentration of sodium silicate is high enough to form the gel, it could decrease the potential of liquefaction, i.e. the liquefaction never take place wherever the grout has reached and turn to gel.

In Fig.4 and 5 the cyclic deformation behaviour of clean sand with CSR=0.15 is shown at the left plots.

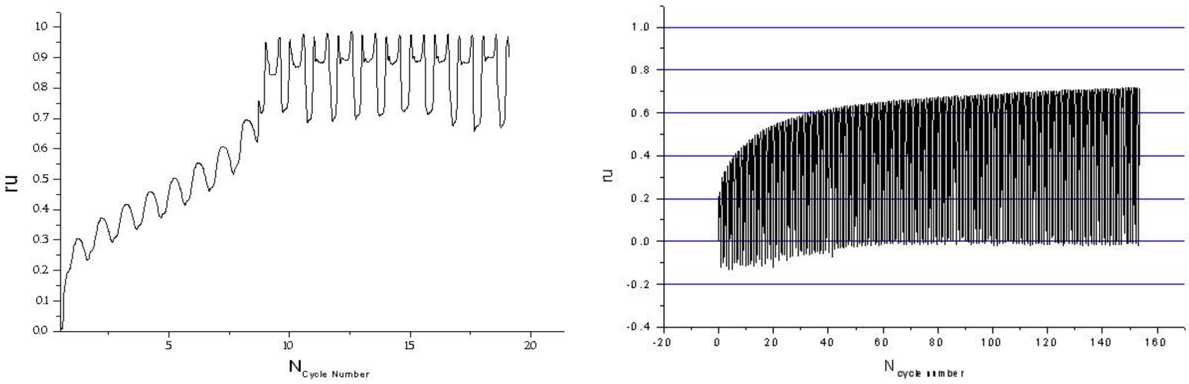

Figure 4. Pore pressure during cyclic loading (left: clean sand, right: treated sand)

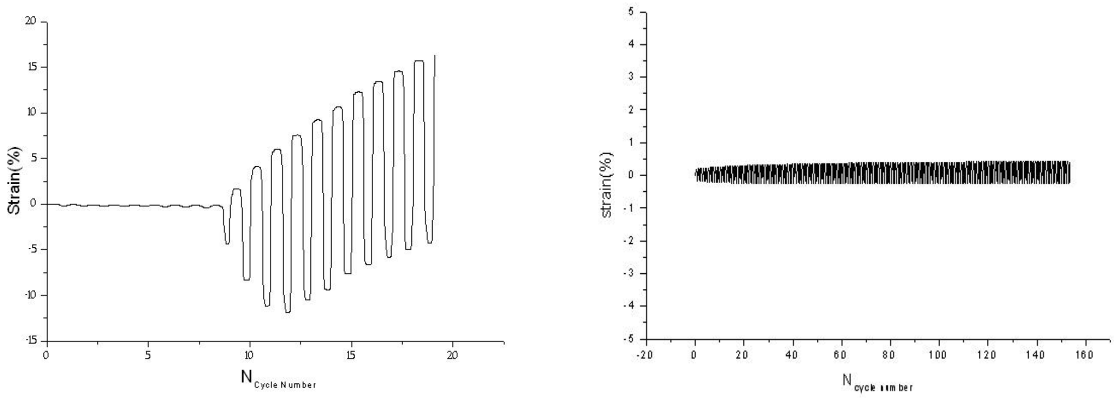

Figure 5. Axial Deformation during cyclic loading (left: clean sand, right: treated sand)

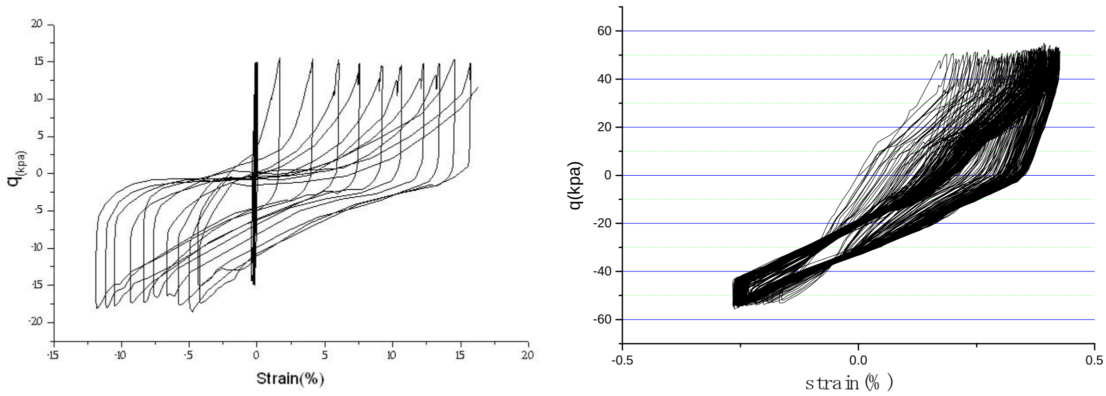

Figure 6. Deviator stress versus axial strain (left: clean sand, right: treated sand)

The cyclic stress ratio is defined as the ratio of the maximum cyclic shear stress to the initial effective confining stress. The untreated sample strained 0.1 percent in 8 cycles and collapsed in 10 cycles. The sample treated with 25 weight percent sodium silicate was tested for 1000 cycles. It strained less than about 2 percent in 13 cycles, about 4 percent in 1000 cycles, and never collapsed. Only the first 150 loading cycles are shown in Figure 4 and 5. These results are typical for samples treated with 25 percent sodium silicate by weight and CSR=0.5. For comparison, a magnitude 7.5 earthquake would be expected to generate about 15 uniform stress cycles.
Overall, treatment with sodium silicate grout significantly increased the deformation resistance of loose sand to cyclic loading.

Monotonic triaxial testing results

As shown in Figs. 3, the results of these tests illustrate the beneficial effect that the grout injection and the concentration of the sodium silicate grout have on the strength and on the stiffness of the soil. They also confirm the following general trends for sodium silicate grouted sand:

• Stiffness and strength increase as the binder content increases;
• The cohesion increase as the concentration of sodium silicate increases, but the friction angel does not change significantly.
Failure occurs with visible shear bands for high confining pressures.

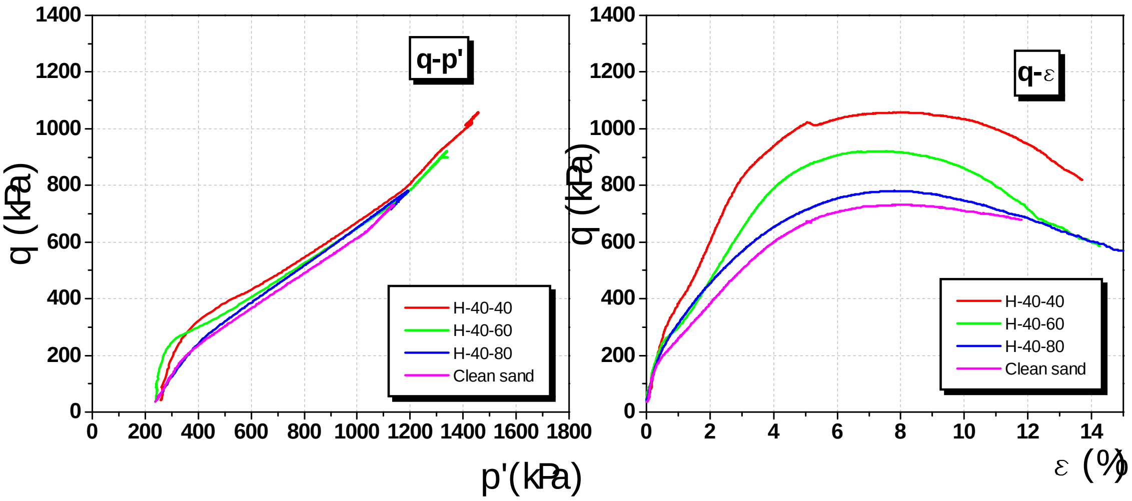

Figure 7. Monotonic triaxial test result with different concentration of sodium silicate

CONCLUSSION

Series of monotonic and cyclic triaxial tests were performed to investigate the influence of sodium silicate grout on the shear strength, deformation properties and liquefaction resistance of liquable sands. It showed that use of sodium silicate grout with concentration more than 25% significantly increases the deformation resistance of liquable sands to cyclic loading. The following conclusions can be drawn.

1. Samples treated with sodium silicate grout have higher shear strength and it increase by increasing the sodium silicate concentration.

2. Untreated samples experience much larger strains in fewer cycles than treated samples and collapse within ten cycles at a CSR of 0.15. In contrast, grouted sand samples experienced very little strain during cyclic loading at CSR of 0.15.

3. To observe the cyclic behavior of treated samples with sodium silicate, they were tested at CSR of 0.5. The strain that accumulated did so uniformly throughout loading and no treated samples collapsed.

4. Samples stabilized with higher concentrations of sodium silicate experienced less strain during cyclic loading than those stabilized with lower concentrations.

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