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Effect of Soils Hydraulic Conductivity on Colloidal Nano-Silica Permeation

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ABSTRACT: Passive site stabilization is a new technology proposed for non-disruptive mitigation of liquefaction risk at developed sites. It is based on the concept of slowly injecting colloidal nano-silica at the edge of a site and deliver stabilizer to the target location using either natural or augmented groundwater flow. Many factors such as stabilizer properties, method of injection, soil type, hydraulic conductivity and porosity are important in the permeation of colloidal silica. In this study, four box models were used to stabilize liquefiable loose mixes of sand with variations in silt content from 0 to 30% with colloidal silica (4.5 wt%) using 5 low-head injection and 2 extraction wells. Then the relation between hydraulic conductivity of soil and duration of colloidal nano-silica permeation was investigated. Results show the amount of hydraulic conductivity strongly affected permeation time of colloidal silica so that a power relation could be suggested between them.

Keywords: *Colloidal nano-silica, Hydraulic conductivity, Liquefaction, Stabilization, Physical model, Silty sand.*

INTRODUCTION

Liquefaction is a phenomenon marked by a rapid and dramatic loss of soil strength, which can occur in loose, saturated liquefiable soil deposits subjected to earthquake motion and result in large deformation and settlements, floating of buried structures, or loss of foundation support. Passive site stabilization is a new technology proposed for non-disruptive mitigation of liquefaction risk at developed sites. It is based on the concept of slowly injecting colloidal nano-silica (colloidal silica) at the edge of a site and deliver stabilizer to the target location using either natural or augmented groundwater flow. Colloidal silica is an aqueous suspension (a sol) of silica (SiO_2) nanoparticles (7-100 nm) that can be made to gel by changing the ionic strength and pH of the dispersion. In diluted solutions, colloidal silica has a low initial viscosity of about 1.5×10^{-3} Pa.s (1.5 cP; water = 1 cp). After gelation of colloidal silica, a firm, resonating gel forms. The density, controllable gel time, and low viscosity make colloidal silica attractive as a potential grouting material for passive site stabilization (Gallagher, 2000, Gallagher& Koch, 2003). Colloidal silica also has excellent durability characteristics (Yonekura & Miwa 1993, Whang, 1995).

It is chemically and biologically inert, and it is non-toxic (Iler, 1979). Colloidal silica was proposed as a replacement for the most commonly used chemical grout, sodium silicate (Yonekura & Kaga, 1992). Persoff *et al*. reported colloidal silica stabilizer is expected to be permanent in typical soil conditions. To whata & Kabahima found that the behavior of loose sand treated with colloidal silica is similar to the behavior of denser untreated sands. Gallagher & Mitchell, Liao *et al*., and Diaz-Rodriguez *et al*. reported that colloidal silica significantly increases the cyclic strength of sands. Physical modeling and centrifuge testing have been done to investigate the ability of diluted colloidal silica (5wt %) to mitigate the liquefaction potential of loose sands (Gallagher & Finstere, 2004, Gallagher *et al.*, 2007, Pamuk, *et al.*, 2007, Gallagher & Lin 2009, Hamderi, M. (2010).

Few field-scales testing of colloidal silica for environmental remediation has been done in small, limited scales (Moridis*et al.*,1996, Noll*et al.*,2007).

Numerical modeling has also been designed to simulate colloidal silica injection in sand using iTOUGH2, MODFLOW, and UTCHEM numerical simulation.

A few number of these numerical models accurately represented the physical experiments (Hamderi & Gallagher, 2013, Hamderi *et al.*,2014).

Although a few studies have investigated passive site stabilization method for treating sands, but treatment of other liquefiable deposits, such as silty sands requires more investigation.

Silty sand is a sandy soil with fine grained silt content. It has low hydraulic conductivity compared to pure sand. In this research, a box model was constructed to investigate the ability of the colloidal silica solution to permeate different mixes of sand with variations in silt content from 0 to 30% in a uniform manner under small gradients imposed by injection and extraction wells. In this process the relation between hydraulic conductivity of soil samples and permeation duration of colloidal silica was discussed.

MATERIALS AND METHODS

In this study, four different liquefiable soil samples were prepared and tested separately in a physical box model. The samples consisted of sand with variations in silt (fine-grained soil) content from 0 to 30%. The sand and silt used to prepare the samples were Firoozkooh No.161 sand and None-Plastic Firoozkooh silt respectively (Firoozkoohis located in north of Iran). Their gradation curves are shown in Fig. 1.

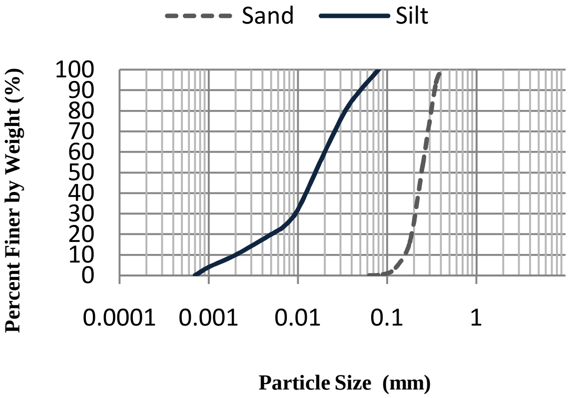

Fig. 1. Grain size distribution for Firoozkooh No.161 sand and Firoozkooh silt

Chemical analysis of Firoozkooh No.161 sand is also shown in Table 1.To prepare the stabilizer material, SIGMA-ALDRICH Ludox®SM-30 wt% (suspension in water) was diluted to 4.5wt%. Table 2 shows the characteristics of Ludox®SM-30 wt% according to SIGMA-ALDRICH product information. For gel time control of the diluted solution, scientific sodium chloride (NaCl) and 6N hydrochloric acid (HCl) were used to adjust the ionic strength and pH, respectively.

Table 1: Chemical analysis of Firoozkooh No.161 sand.

Mineral	Content
SiO_2	96-98.8%
Fe_2O_3	0.2-0.7%
Al_2O_3	0.5-1.65%
Cao	0.2-0.5%
Na_2O	0.03-0.08%
K_2O	0.03-0.10%

Table 2: Characteristics of Ludox® SM-30 wt% colloidal silica.

Index property	Content
Silica concentration	30 wt%
Average particle size	8 nm
Specific area	320-400 m^2/g
pH	9.7-10.3
Density at 25º	1.22 g/ml
Viscosity	5.5 cP

The box model used for the tests had three compartments, a central chamber for soil placement and two outer reservoirs for water placement and groundwater control. The box was constructed of 10 mm thick Plexiglas with dimensions of 125 × 30 cm and a height of 30 cm. The flow length through the soil sample was 60cm and each water reservoir was 20 cm long. Screen with a No. 300 mesh size was used between the water and soil compartments. A filter layer of coarse gravel with a thickness of 10 cm was designed to be placed between the screens and the liquefiable soil sample to prevent soil loss from the central chamber into the reservoir.

The schematic pattern of the model setup is shown in Figure 2. The left and right sides of the soil chamber are the upstream and downstream chambers, respectively. Sampling ports in the soil chamber are small taps, and their input sections are covered with filter paper.

These taps are used to extract fluid samples across the soil profile to measure changes in the pore fluid chemistry as the colloidal silica is transferred into the soil medium. Five injection and two extraction wells were constructed from 20-mm PVC pipe.

The injection wells had four 5-mm injection ports arranged in one vertical column at depths of 3.5, 6, 8.5, and 11 cm below the soil surface.

The ports were covered with a No. 16 mesh and a layer of propylene granules with a width of 6 mm. This layer prevents soil loss into the injection wells, while facilitating the flow process of colloidal silica from the injection ports into the soil sample. The injection wells intervals were 5 cm and the ports were in the downstream direction. These wells were located 15 cm from the filter layer (coarse gravel) and had a distribution bay to maintain a constant supply of colloidal silica to the wells.

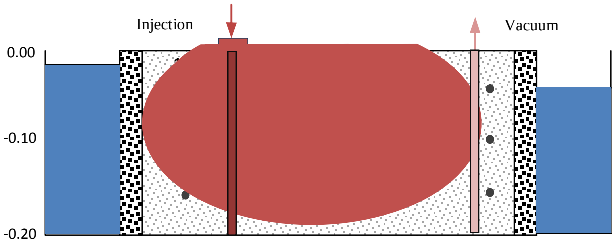

Fig. 2. Schematic pattern of model setup

Two extraction wells were used to withdraw fluid from the soil formation at a rate of 10 mL/min with a small suction apparatus. The extraction wells had seven 5-mm- diameter ports covered with a No. 300 mesh. The ports were uniformly distributed along the length of the well, starting at a depth of 2.5 cm below the soil surface. The wells were located adjacent to the downstream filter layer edge of the model at equally spaced intervals. The extraction ports were in the upstream direction.

The model was tested for four different liquefiable soil samples. The samples consisted of sand with variations in silt (fine-grained soil) content from 0 to 30%. The characteristics of the samples are shown in Table 3. To ensure of the accuracy of the results, two box model tests were repeated.

For each test, the soil chamber was filled by pouring the soil sample to a height of 20 cm under loose soil conditions (at a relative density of approximately 20%). After soil placement, the upstream reservoir was filled with water to saturate the soil. After saturation, an overall gradient of 0.03 was established using the constant-head flow in each reservoir chamber. After the overall gradient was established, the colloidal silica solution (4.5 wt%, 0.1 normality of NaCl) was introduced to the soil using injection wells as the stabilizer material.

The pH was adjusted as viscosity remained approximately 1.5 cP during colloidal silica delivery in each box model test (see Table 4).

Table 3: Characteristics of soil samples in box model testing.

Sample	Sand content (%)	Silt content (%)	Relative Density (%)	Hydraulic conductivity (cm/s)
SM0	100	0	20	4.74×10^{-2}
SM10	90	10	20	1.21×10^{-2}
SM20	80	20	20	3.33×10^{-3}
SM30	70	30	20	6.81×10^{-4}

During colloidal silica delivery, a constant head of 21 cm from the bottom of the soil chamber was maintained in the injection wells. This head resulted in colloidal silica movement in both upstream and downstream directions.

As described above, in this testing program, theinjection system, colloidal silica stabilizer properties and relative density of soil samples were similar in all box models and the single variable parameter was hydraulic conductivity of soil samples.

Table 4: Properties of dilute colloidal silica solution used in this study.

Index property	Content
Silica concentration	4.5 wt%
NaCl	0.1 Normality
pH	6-6.7
Gel time	24-48 hour
Viscosity	1.5 cP

RESULTS AND DISCUSSION

The advancement of colored colloidal silica in box models testing was determined with visual monitoring and measurement of extracted pore fluid sample concentrations. A photograph of the box model test for colloidal silica progression in the soil sample of SM10 is shown in Fig.3.

During the periods of 4, 9, 27, and 45 hours, 18 liters (approximately 1.2 pore volumes) of colloidal silica solution (4.5wt%) was delivered to the soil samples of SM0, SM10, SM20, and SM30 in box model testing respectively. Because of variance in hydraulic conductivity, under identical conditions, a considerable difference in delivery time of colloidal silica occurred. The increase in delivery time of the colloidal silica in silty sand samples as a function of the hydraulic conductivitycan be described by a time-hydraulic conductivity curve (Fig. 4).

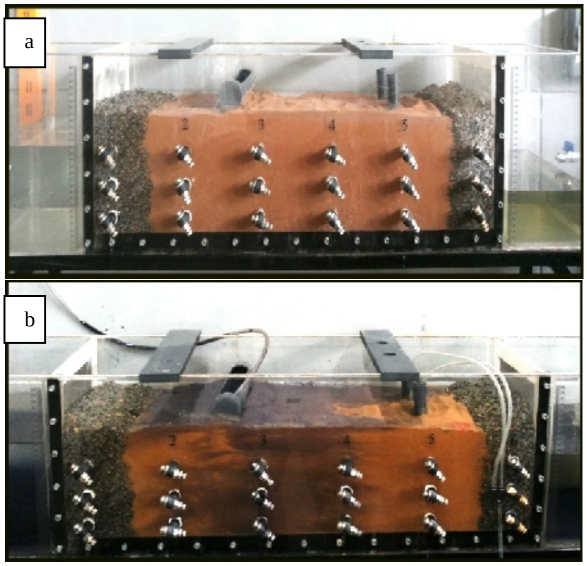

Fig. 3. Box model for colloidal silica delivery study; (a) before injection; (b) during injection

The curve suggests the use of a power function of the form

$$t = mk^{n} \qquad (1)$$

Which $t$and k are delivery time of one liter of colloidal silica in silty sand formation (at described conditions of this study) and hydraulic conductivity respectively, and, m and n are fitting parameters.

The curve in Figure 5 also suggests the following function:

$$k = ae^{sb} \qquad (2)$$

Which $k$and s are hydraulic conductivity and silt content of silty sands sample respectively, and, a and b are fitting parameters. It is shown the hydraulic conductivity of samples followed an exponential function with silt content.

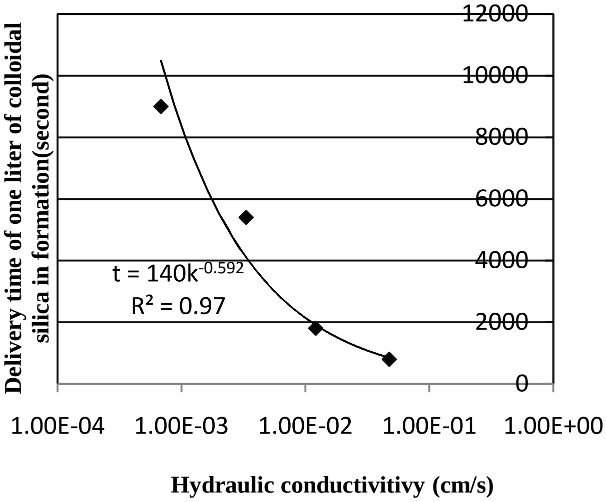

Fig. 4. Effect of hydraulic conductivity on the delivery time of one liter of colloidal silica in silty sand formation at box models

It is shown the amount of silt strongly affected on hydraulic conductivity of silty sands and the amount of hydraulic conductivity of soils was so effective in permeation time of colloidal silica in formation.

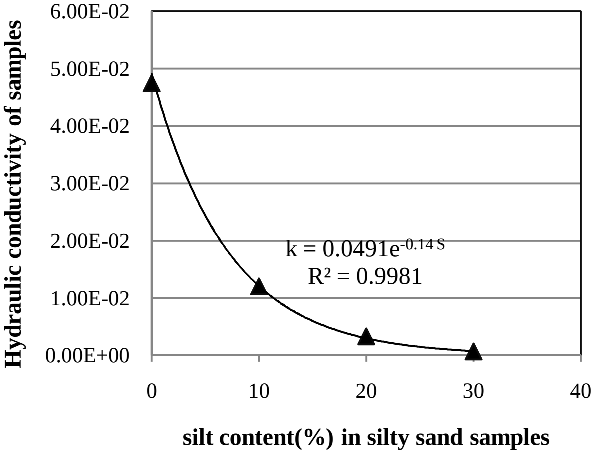

Fig. 5. Effect of hydraulic conductivity on the delivery time of one liter of colloidal silica in silty sand formation at box models

CONCLUSION

Physical modeling was performed to study the permeation of nano colloidal silica in sand with different content of fine grained soil (silt) in a low-gradient groundwater flow field. According to the results, there is an exponential relation between the hydraulic conductivity of silty sands and silt content. More over the amount of hydraulic conductivity strongly affected permeation time of colloidal silica, the delivery time of colloidal silica in formation and hydraulic conductivity shows a power relation at defined conditions. For passive site stabilization, a 4.5 wt% concentration of colloidal silica is expected to be able to adequately mitigate the liquefaction risk.

REFERENCES

Diaz-Rodriguez, J.A., Antonio-Izarras, V.M., Bandini, P. & Lopez-Molina, J.A. (2008). Cyclic strength of natural liquefiable sand stabilized with colloidal silica grout. *Canadian Geotech. J.* **45**, No. 10: 1345-1355.

Gallagher,P.M. (2000). Passive site remediation for mitigation of liquefaction risk. *Ph.D Dissertation, Virginia Polytech. Inst. and State Uni.*, Blacksburg.

Gallagher, P.M. & Mitchell, J.K. (2002).Influence of colloidal silica grout on liquefaction potential and cyclic undrained behavior of loose sand. *Soil Dynamics and Earthquake Engg*.**22**, No. 9-12:1017-1026.

Gallagher, P.M. & Koch, A. J. (2003). Model testing of passive site stabilization: A new technique. *Proc.3rd Int. l Conf. on Grouting and Ground Treatment, New Orleans* **2**: 1478-1490.

Gallagher, P.M., & Finstere, S. (2004). Physical and numerical model of colloidal silica injection for passive site stabilization. *Vadose Zone J.* **3**, No. 3: 917-925.

Gallagher, P.M., Pamuk, A. & Abdun, T. (2007). Stabilization of liquefiable soils using colloidal silica. *J. of Materials in Civil Engg.***33**, No. 1: 33-40.

Gallagher, P.M., Conlee, C.T. & Kyle, M. (2007). Full scale testing of colloidal silica grouting for mitigation of liquefaction risk. *J. of Geotech. And Geoenvironment. Engg.* **133**, No. 2: 186-196.

Gallagher, P.M. & Lin, Y. (2009). Colloidal silica transport through liquefiable porous media. *J. of Geotech. and Geoenvironmen. Engng*.**135**, No. 11: 1702–1712.

Hamderi, M. (2010). Pilot scale modeling of colloidal silica delivery to liquefiable sand. *Ph.D. dissertation, Drexel University. USA.*

Hamderi, M. & Gallagher, P.M. (2013). An optimization study on the delivery distance of colloidal silica. *Scientific Research and Essays.***8** (27): 1314-1323.

Hamderi, M., Gallagher, P.M. & Lin, Y. (2014). Numerical model for colloidal silica injected column tests. *Vadose Zone J.* **13**, No. 2: 138-143.

Iler, RK. (1979). *The Chemistry of Silica: Solubility, Polymerization Colloid and Surface Properties, and Biochemist Try*. New York : Wiley.

Liao, H.J., Huang, C.C., & Chao, B.S. (2003). Liquefaction resistance of a colloidal silica grouted sand. In L.F.Johnsen*et al.* (Ed.), *Grouting and grout and deep mixing* (pp. 1305-1313). *Proceeding of the Third International Conference. New Orleans, LA. Reston, VA: ASCE.*

Moridis, G.J., Apps, J., Persoff, P., Myer, L., Muller, S., Yen P & Pruess, K. (1996). A field test of a waste containment technology using a new generation of injectable barrier liquids. Spectrum **96**, Seattle, WA.

Noll, M.R., Bartlett, C., Dochat, T.M. In situ permeability reduction and chemical fixation using colloidal silica.(1992). *Proceedings of the Sixth National Outdoor Action Conference (pp. 443–57).Las Vegas, NV.*

Persoff, P., Apps, J., Moridis, G. & Whang, J. M. (1999). Effect of dilution and contaminants on sand grouted with colloidal silica. *J. of Geotech.l and Geoenvironment. Engg*. 125, No. 6: 461–469.

Pamuk, A., Gallagher, P.M. & Zimmie, T.F. (2007).Remediation of piled foundations against lateral spreading by passive site stabilization technique. *Soil Dynamic and Earthquake Engng*.**27**, No. 9: 864–874.

Towhata, I. & Kabashima, Y. (2001).Mitigation of seismically-induced deformation of loose sandy foundation by uniform permeation grouting.*Proc. Earthquake Geotech.Engng Satellite Conf., 15th Int. Conf. of Soil Mech. and Geotech. Engg, Istanbul*, 313-318.

Whang, JM. (1995). Chemical Based Barrier Materials. *In Assessment of Barrier Containment Technologies for Environmental Remediation Applications*(Rumer RR, Mitchel JK, Editors). Section 9, Springfield, VA: National Technical Information Service.

Yonekura, R. & Miwa, M. (1993). Fundamental properties of Sodium Silicate based grout. *Proc.11th Southeast Asia Geotech. Conf.*, Singapore, pp. 439-444.

Yonekura, R. & Kaga, M. (1992).Current chemical grout engineering in Japan. In R.H. Borden et al. (Ed.), *Grouting, soil improvement and geosynthetics* (pp. 725-736). New York: ASCE.