Stabilization of Liquefiable Soil using Colloidal Silica: A Review

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***Abstract*: From the past few decades it was widely recognized that earthquakes are among the most severe natural disasters causing significant damages of earth structure, settlement of buildings, lateral spreading and densification which causes the vertical settlements. The phenomenon of liquefaction is associated with a condition of zero effective stress due to progressive increase in pore water pressure which results from the tendency to densify the sand structure subjected to cyclic loading. The generation of excess pore pressure under undrained loading condition is an important reason for all liquefaction phenomena. Globally many researches carried out studies on liquefaction assessment based on different methods. From the field of nanotechnology, colloidal silica (CS) has been introduced for ground improvement and liquefaction mitigation as it possesses great ability to restrain pore pressure generation during seismic events. It has the advantages of being a cost-effective, low disturbance, and environmentally friendly method.**

Keywords: Collodial silica, Liquefaction mitigation.

1. INTRODUCTION

Liquefaction is a phenomenon in which the strength and stiffness of a soil is reduced by earthquake shaking or other rapid loading. It occurs in saturated soils, that is, soils in which the space between individual particles is completely filled with water. This water exerts a pressure on the soil particles that influences how tightly the particles themselves are pressed together. Prior to an earthquake, the water pressure is relatively low. However, earthquake shaking can cause the water pressure to increase to the pointwhere the soil particles can readily move with respect to each other. When liquefaction occurs, thestrength of the soil decreases and, theability of a soil deposit to support foundations for buildings and bridgesis reduced. However, liquefaction is more likely to occur when the stratum is mainly composed of silty sand or fine sand.

With the development of nanotechnology, nanomaterials havebeen proposed by many researchersto be introduced into ground treatment to improve mechanical properties and mitigate liquefaction risk. The presence of even very small amount of nanomaterial can have significant effects on the engineering properties of soil. The use of nanoparticles in a soil mixture increases strength, swelling index and compressibility as well as decreases permeability, liquefaction potential, settlement and volumetricstrains. This paper, discusses on the studies done with nanoparticles in soil, their properties, their effects on soil and the equipment used in nanotechnology.

Among those advanced nanomaterials cheapest and most widely used one in soil treatment is colloidal silica (CS). CS is a kind of powerful material that can be used for passive site stabilization, which isa relatively new technique that hasbeen proposed by Gallagher (2002) as a nondisruptive treatment to mitigate liquefaction risk.

1.1 COLLODIAL SILICA

Colloidal silicas are suspensions of fine amorphous, nonporous, and typically spherical silica particles in aliquid phase which are suspended in an aqueous phase that is stabilized electrostatistically with particle densities in the range of 2.1 to 2.3 g/cm^3. Colloidal silica (CS) is an aqueous suspension of microscopic nanosilica, extracted from saturated solutions of silicic acid. In general, the particle size of nanosilica isuniform, ranging from 7–22 nm. CSis nontoxic, chemically and biologically inert and environmental friendly. When diluted to a 5% concentration by weight, the viscosity of CS solution is only 1.5-2 cP. With the addition of an electrolyte, a CS solution can be destabilized in order to start the gelation process. From experimental studies, it was found that CS has the advantages of low initial viscosity, controllable gel times, good long- term mechanical stability and minimal disruption to infrastructure due to the small particle size and surface charge of the silica particles.

This paper reviews the main experimental studies and findingswith colloidal silica for soilimprovement and liquefactionmitigation.

2. LITERATURE REVIEW

Jiji Krishnan et al. (2021): Colloidal silica treatment in loose sand helps to improve the strength and reduces hydraulic conductivity. As CS can be used in already constructed areas it in bore beneficial, particularly in urban areas,as it's a new non-conventional technique to solve existing engineering problems in the field of liquefaction mitigation. The presence of colloidal silica in sand provides a weakly cemented bond in the colloidal silica grouted sand matrixand generates a stiffer and denser matrix which can be utilized in applications such as contaminant barrier systems, reservoir fluid-flow control systems in oil fields, tunnel grouting, dams, pavements, andairfields.

Yubin Zhang (2019): The paper focuses on the types and hazards of earthquake liquefaction and its mechanism. The factors affecting liquefaction and the critical conditions of liquefaction are discussed. Based on the dynamic characteristics of earthquake ground motion, two evaluation factors of earthquake liquefaction wereproposed.

Mingzhi Zhao et al. (2019): Discusses a relatively new technique that has been proposed by Gallagher (2002) as a nondisruptive treatment to mitigate liquefaction risk, passive site stabilization technique. The most critical point in passive site stabilization is the smooth delivery ofthe grouting materials.

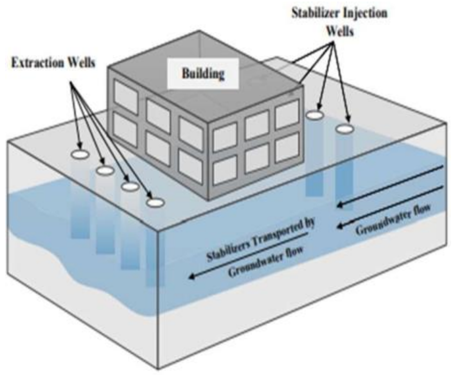

Figure 1: Passive site stabilizationconcept [Mingzhi Zhao et al.]

The critical factors that can significantly influence CS transport and the CS strengthening effect are studied which concluded that CS concentration and curing time are the two dominant factors that determine the ground improvement effect.

Christopher Wong et al. (2018): The drained stress-strain behaviour of CS gel, sands grouted with CS and clay mixed with CS are presented in this paper. CS reduces the overall volumetric deformation during compression and increases the stiffness, when compared with untreated sand. It reduces the overall volumetric deformation and enhancesthe peak shear strength.

Georgia I. Agapoulaki et al. (2018): This paper studied on the rheological response of colloidal silica grout for passive site stabilization against liquefaction. From the study it was concluded that temperature imposes a decreasing effect on gel time, similarly to the effects of CS (%) and salt normality. Viscosity-versus-time curve of colloidal silica solutions were able to predict by the proposed charts and equations in the study.

Maithili K L (2017): The paper discusses on the soil improvement methods that are commonly employed to reduce the effects of liquefaction in soil. New concepts like passive site remediation, microbial geotechnology, inducedpartial saturation have been proposed. Methods like colloidal silica grouting, bentonite suspension grouting, biocementation, air injection, biogas, and mitigation using geomaterials are the conceptsexplained in the study.

P. Bandini et al. (2008): CS impregnation can significantly increase the cyclic strength of natural silty sands. The gain in cyclic resistance due to the CS grouting is influenced by the initial relative density of the sand, the initial effective vertical stress, and the CS concentration. The CS grouting also has effects on the pore pressure development and deformation resistance during cyclic loading.

Patricia M. Gallagher et al. (2007): A centrifuge box model experiment was performed loose Nevada 120 sand treated with colloidal silica grout at a concentration of 6% by weight. it is evident that treatment of loose sands with dilute colloidal silica greatly reduces their liquefaction potential.

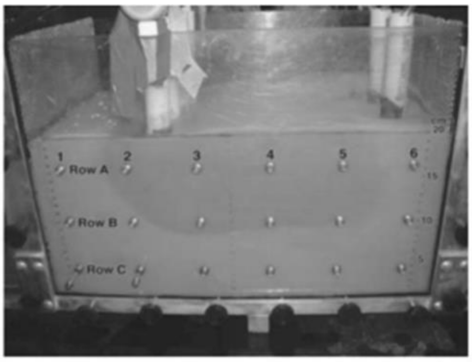

Figure 2: Box model test[Mingzhi Zhao et al.]

The study concluded that in low concentrations it greatly increases the deformation resistance of loose sands subjected to earthquake shakings. Also CS is a cost effective stabilization method for liquefiable soils, non-toxic and chemically stable.

Patricia M. Gallagher et al. (2005): The study mainly focused on the ability to deliver CS solutions uniformly into columns of liquefiablesoil, with subsequent gelation to mitigate the liquefaction potential. Four column tests in loose sand with density 40% was treated with

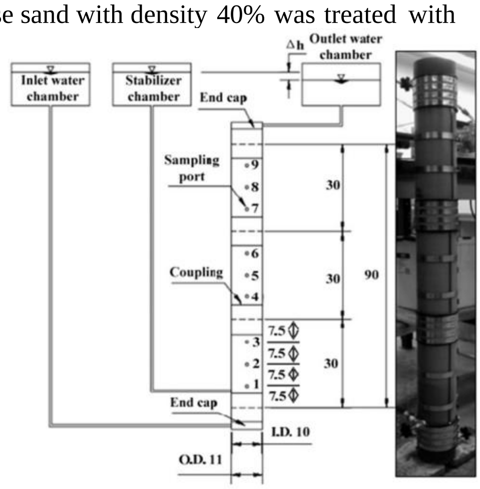

Figure 3: Schematic and photo of thecolumn test [Mingzhi Zhao et al.]

colloidal silica at a concentration of 5% weight. The paper concludes that Stabilizer delivery is most efficient when the viscosity of the stabilizer is in the range of less than 3.6 cP. Unconfined compression testsshowed that 5% weight of silica was adequate to mitigate the liquefaction risk.

V.M. Antonio Izarraras et al. (2004): Study was conducted on loose Lazaro Cardenas sand to find the effect of density, colloidal silica content, pore pressure response and shear strain on the liquefaction resistance of treated specimens. Study concluded that small amount of CS significantly increases the cyclic strength of untreated sands. In loose sands the addition of CS greatly reduces the potential for particle movement and reorientation. Treated loose sand and untreated dense sand had same behaviors.

3. CONCLUSION

The current paper reviews the literature related to colloidal silica treated sand, new nonconventional stabilisation techniques to enhance the engineering properties and tomitigate soil liquefaction. It is clear that the behavior of soil treated with CS grout is very complex.

The conclusion from the studies are:

- CS has attractive properties which includes low cost, no toxicity, wide range of gel time, and low viscosity.
- CS grout can be successfully transported through porous media.
- Effects related to grout viscosity increase over time and grout sinkingneed to be considered in design.
- CS improves the liquefaction resistance of liquefiable soil.
- The strength of the treated material increases with the increase in both CS content and gel aging.
- The effects of CS grouting at low- medium strain levels have not been well defined.
- The compressibility of the treated material is greater than that of the untreated one
- Hydraulic conductivity of the soil decreases with CS content.

REFERENCES

[1] Eldhose M Manjummekudiyil et al. (2021), “Liquefaction Susceptibility Of Soil InErnakulam District”, International Research Journal of Engineering and Technology, Volume: 08 Issue: 06

[2] Chong Zhang et. al. (2020), “State-of-the-art of colloidal silica-based soil liquefaction mitigation: an emergingtechnique for groundimprovement”, applied science journal

[3] M. Akhila et al. (2019), “Liquefaction susceptibility of central Kerala”, SN Applied Sciences 1:583, Research Article

[4] Hongzhi Cui (2019), “Soil liquefaction mitigation in Geotechnical engineering: An overview of recently developed methods”, Soil Dynamics and Earthquake Engineering, pg:273–291

[5] Maithili K L (2017), “A Discussion of Liquefaction Mitigation Methods”, International Research Journal of Engineering and Technology, Volume: 04 Issue: 12

[6] Huang, Y. (2013), “Review of soil liquefaction characteristics during major earthquakes of the twenty first century”.

[7] Conlee, C. T. (2010), “Dynamic properties of colloidal silica soils using centrifuge model tests and a full-scale field test.” Ph.D. thesis, Drexel Univ.

[8] Díaz-Rodríguez et al. (2008), “Cyclic strength of a natural liquefiable sand stabilized with colloidal silica grout”, Can. Geotech.

[9] Ahmet Aamuk et. al. (2007), “Stabilization of liquefiable soils using colloidal silica groutparticles”, Journal of materials in civil engineering

[10] Lin, Y. (2006), “Colloidal silica transport mechanisms for passive site stabilization of liquefiablesoils.” Ph.D. thesis, Drexel Univ.

[11] Gallagher (2007), “Stabilization of Liquefiable Soils Using Colloidal Silica Grout”, Mater. Civ. Eng.

[12] Gallagher et al. (2007), “Stabilization of liquefiable soils using colloidal silica grout.” J. Mater. Civ. Eng.

[13] Patricia M. Gallagher et al. (2004), “Physical and Numerical Model of Colloidal Silica Injection for Passive Site Stabilization”, Soil Science Society of America, Vadose Zone Journal.

[14] Gallagher, P. M. (2000), “Passive site remediation for mitigation of liquefaction risk.” Ph.D. thesis, Virginia Polytechnic Institute andState Univ.