Proceedings of the 21st ICSMGE, Vienna, Austria, 14 – 19 June 2026. Pistrol, Adam & Schweiger (eds.)
Published by: ÖGG, Austrian Society for Geomechanics, Salzburg, Austria, ISBN 978-3-9503898-4-5
https://doi.org/10.53243/ICSMGE2026-984

Stabilization of dispersive soils using nano-silica

Waleed Ahmed Tanoli, **Syed Kamran Hussain Shah**, Numan Ahmed
National Institute of Transportation, Risalpur, (NUST) Pakistan, kamran.hussain@nit.nust.edu.pk

Malik Adnan Anwar
The University of Newcastle, Callaghan, Australia

Umair Ali
King Fahd University of Petroleum and Minerals, Dhahran, Kingdome of Saudi Arabia

Khawaja Adeel Tariq
University of Engineering & Technology, Lahore (Narowal Campus)

ABSTRACT: Dispersive soils are highly problematic due to their tendency to erode even in still water. This erosion occurs rapidly because of the high concentration of sodium (Na^+) ions in these soils. When encountered during the construction of earth structures, earthen dams and similar structures pose a serious risk of erosion and failure. This study investigates the effect of nano-silica on dispersive clay. Nano-silica was added to the clay in varying percentages (0.2%, 0.4%, 0.6% and 0.8%). Several tests were performed to evaluate the impact of nanoparticles on the clay's properties. Several laboratory tests like Atterberg's Limits, Standard Proctor Test, Pinhole test, Unconfined Compression Strength (UCS), and indirect tensile strength (ITS) were performed to assess the impact of nano silica on the dispersive nature of the soil. The findings revealed that both nano-silica treatments significantly improved the properties of dispersive soils. When used together, these methods achieved better stabilization results, reducing soil dispersity by increasing finer particles.

KEYWORDS: Dispersive soils, Soil erosion, Pin hole test, Nano silica.

1 INTRODUCTION

Dispersive soils are often encounter earth materials prone to deflocculation and apparent erosion in the presence of low-salinity water. This natural instability may lead to piping, extreme instability failures, and environmental devastation even at small hydraulic gradients. (Masrour et al., 2021). Every time dispersive clay is mixed with water, the electrochemical affinity between the clay particles drops to a minimum level and thus leads to erosion. Dispersive soils can have severe negative impacts, including the potential to compromise construction projects, such as piping in earth dams. (Jansen, 1988). Recent research indicates that amorphous nano silica (NS 10-100 nm) is a highly active pozzolan and a source of large numbers of nucleation sites of calcium silicate hydrate (C-S-H) gels has good potential for being employed as an ultrafine filler. (Abisha, 2025). Nano-silica (nanoSiO_2) has recently been nominated as a potential novel alternative soil stabilizer, and due to its miniscule particle size (nanoscale) and large surface area, it is used to alter the soil fabric at the micro-scale level. When used at low concentration (usually 0.5%-2 % of dry mass), it has proved to provide significant geotechnical advantages on a variety of clay and dispersive soils. (Jassim et al., 2022). Nano silica addition was reported to have reduced the possibility of dispersivity by 100 percent in 14 days after the addition of a combination of 5 percent pozzolan and 1.5 percent cement to a dispersive clay. It was noticed that the dispersivity potential of dispersive soils could also be reduced by 52% in the case of the addition of lignosulfonate, which is an industrial by-product of the wood and paper processing industries (Vakili et al., 2018). Nano silica influence is actualized in two ways: a filling effect plus a chemical reaction caused by a cation exchange between clay particles (Abbasi, Farjad and Sepehri, 2018). Macro-scale tests with non-dispersive clays show persistent declines of 20-45 % in plasticity index, 2-5 % increases in maximum dry density, and twofold gains in unconfined compressive strength with the addition of just 0.4-1.0 % NS into the soil mass (Changizi and Haddad, 2017) . The addition of nano silica induces an improvement in the unconfined compressive strength and shear strength of soil. It enhances the parameters of compaction and reduces the plasticity of soil. Briefly, nano-silica has tremendous impacts on soil characteristics (Lo et al., 2015). During recent years, soil improvement is accomplished with the help of nanomaterial such as nano-silica. Nano-silica increases strength of fine-grained soils. It is also suggested that nano-silica can be used as a grouting compound in liquefaction-prone soil (Ali Zomorodian et al., 2017).

2 MATERIALS AND METHODOLOGY:

2.1 *Soil:*

The soil used in this research was collected from Punjab, Pakistan. Figure 1 shows the particle size distribution of the soil under study. It shows that 78.4% of the particles passed through the no. 200 (0.075mm) sieve and categorized as low plastic clay 'CL' according to Unified Soil Classification system. To check the dispersity potential of the soil Pinhole Test ASTM D4647 was performed.

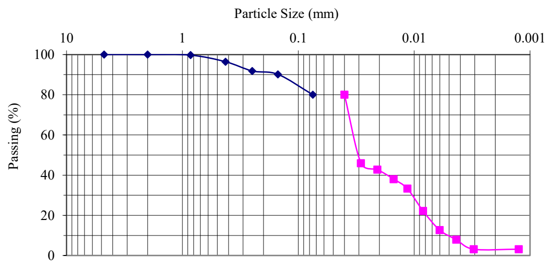

Figure 1 Particle size distribution of a base soil

2.2 *Nano Silica:*

The nano silica in the study was a white powder of amorphous form sourced from China. Its average pore diameter is 7nm, with an average size is 14~36nm, with a purity of 98% and a high specific surface area ranging approximately 580±20 m2/g, and a bulk density of 0.10~0.15 g/cm³.

2.3 *Methodology and Tests Performed:*

This study was conducted in two phases. In phase I, tests were performed on base soil, and in phase II, nano silica was added to the base soil, and then tests were performed after curing for 14 days. To assess the physical behavior of soil grain size distribution test, Atterberg's limit test, and specific gravity test were performed on the untreated and nano silica-treated samples. Likewise, the Pinhole test, the UCS test, and the ITS tests were performed according to their respective ASTM Standards after 14 days of curing. Samples were prepared by mixing four different percentages of nano silica, i.e., 0.2%, 0.4%, 0.6%, and 0.8% by dry weight of the soil.

3 RESULTS AND DISCUSSIONS

3.1 *Atterberg's Limits:*

Figure 2 shows the result of the Atterberg limit test. Results indicate that the addition of nano silica reduces the liquid limit while the plastic limit was increased, which resulted in an overall decrease of plasticity index (P.I). At 0.8% nano silica, a maximum decrease in P. I was observed. It can be seen from the results that the rate of change of Atterberg limits decreased in specimens with more than 0.8% nano silica content with no significant effect on plasticity properties. It can be ascribed to the very fact that further increment of the nano silica content results in the nonhomogeneous mixtures. (Bahmani et al., 2014). In can also be presumed that the absorption of more water by nano-silica leads to a reduction in PI value because of the high surface area and the surface charge properties of nano-silica (Kalhor et al., 2019).

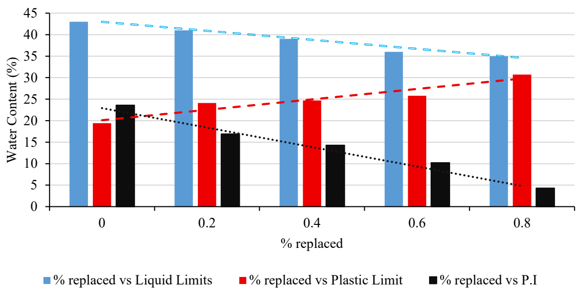

Figure 2 Atterberg's Limit test results for nano-silica treated samples

3.2 *Standard Proctor Test:*

Figure 3 shows that the maximum dry density (ρ_{dmax}) of the soil decreases with an increase in nano silica content, while the optimum moisture content increases. Due to the light weight and density of nano silica, the overall density of the soil decreases. At 0.8% nano silica lowest ρ_{dmax} was observed, and the optimum moisture content was higher. The two main reasons that affect the ρ_{dmax} are cation exchange and flocculation. Flocculation in the soil creates larger voids that are then filled by finer particles. As the specific gravity of the nano silica (2.4) is lower than that of the soil (2.62), this is because of the fineness of the nano silica, which fills the voids present in the soil.

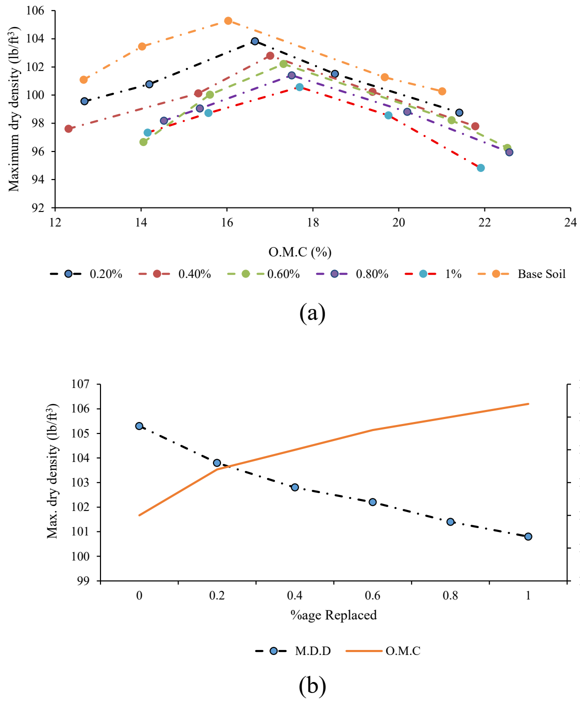

Figure 3 (a) Compaction test results of untreated and treated soil, (b) ρ_{dmax} and O.M.C. variation of treated samples

3.3 *Pinhole Test:*

For the identification of dispersive soils Pinhole test is used to describe the erodibility/dispersivity of a compact specimen of a soil where water is allowed to pass through the small hole, made at the center specimen. This test has been regarded as one of the most dependable physical tests to check the dispersivity of soil because this test represents a scenario of water draining down a pipe/crack in the ground (Sherard, Dunnigan, and Decker, 1976). It is observed that the addition of nano silica affected and reduced the dispersity potential. The test was on sample cured for 14 days performed under 4 different heads (50mm,180mm, 320mm, and 600mm) that were constantly maintained during the test. It was observed that the addition of nano silica reduced the dispersity potential, and this kept decreasing with increasing no. of curing days. At 0.8% nano silica, the dispersity potential against the head 50mm and 180mm was zero, and the soil showed non-dispersive behavior as there was no change in diameter, and the physical appearance was clear as well. Against higher heads, there was still little dispersive behavior.

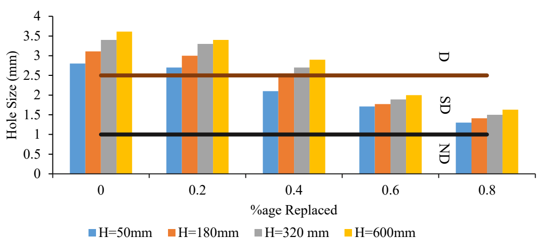

Figure 4 Pinhole Test Results after 14 days of curing

3.4 *Mechanical Characteristics:*

Fig. 5 shows the results of how nano silica affected soil strength after 14 days of curing. Unconfined compressive strength (UCS) tests were conducted to evaluate the mechanical behavior of the untreated (base) soil and the soil treated with 0.8% nano-silica. Compared to the base soil, the nano-silica-treated soil (0.8%) achieved significantly higher UCS values of 200.0 kPa at 14 days curing. This shows a significant increase of about 170.5% in 14 days as compared to the untreated soil. These outcomes indicate how nano-silica works to boost or improve the strength development of dispersive soils, especially when the curing time is long.

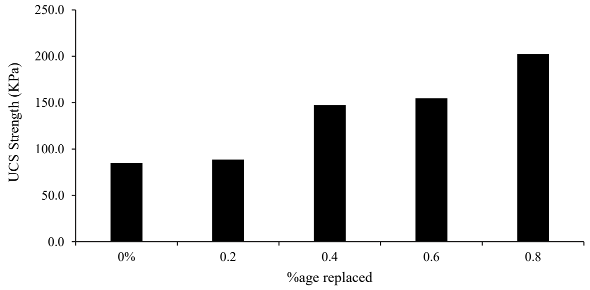

Figure 5 UCS results of untreated and treated soils

The addition of nano articles can increase the tensile strength of the soil. To assess the effect of nano-silica addition on the soil's tensile strength, samples were prepared by incorporating varying percentages of nano-silica and tested after curing for 14 days. Figure 6 shows the result of the Indirect tensile strength test (ITS). After being treated with nano-silica, the soil's ITS also showed a notable improvement. The ITS value at 0% replacement (untreated condition) was 10.0 kPa after 14 days of curing. The ITS was approximately 35.0 kPa with the addition of 0.8 % nano-silica, and so it improved by approximately 350%. This significant improvement demonstrates the promising prospect of using nao silica for tensile resistance by strengthening inter-particle bonds and decreasing the soil's propensity to disperse.

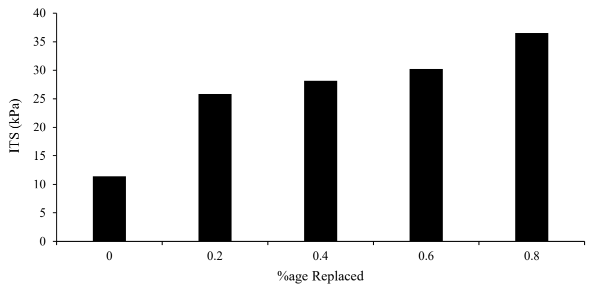

Figure 6 The ITS results of untreated and treated soils for different curing periods.

4 CONCLUSIONS

This experimental study revealed that nano silica is a great contributing factor to enhance the engineering characteristics of dispersive soils. With increasing nano silica content (0.2% to 1%), a notable reduction in liquid limit and an increase in plastic limit were observed, resulting in a decreased plasticity index. Moreover, the potential of dispersivity of the soil was minimized, the soil was observed to be non-dispersive with low hydraulic heads, slightly dispersive at the higher heads and at 0.8 % nano silica content. Compaction characteristics showed a general trend of decreased Maximum Dry Density (MDD) and increased Optimum Moisture Content (OMC), which can be attributed to the fine particle size and pozzolanic activity of nano silica. Mechanical strength parameters improved considerably, as the Unconfined Compressive Strength (UCS) increased by 179% after 14 days of curing. Similar improvement in indirect tensile strength was also observed thus corroborating increased load bearing capacity of the treated soil.

Overall, nano silica was found to be a promising additive to strengthen and decrease dispersity of soils that cause a problem, but with limited loss of ductility. These results indicate its effectiveness in geotechnical operations as a long-lasting and effective soil stabilizer.

5 ACKNOWLEDGEMENTS

The author gratefully acknowledges the National Institute of Transportation (NIT), Risalpur, National University of Sciences and Technology, Pakistan for providing the laboratory facilities and the support of the lab staff during this research.

6 REFERENCES

Abbasi, N., Farjad, A. and Sepehri, S., 2018. The Use of Nanoclay Particles for Stabilization of Dispersive Clayey Soils. Geotechnical and Geological Engineering, [online] 36(1), pp.327–335. https://doi.org/10.1007/S10706-017-0330-9/FIGURES/6.

Abisha, M.R., 2025. Experimental analysis of clay soil with nanosilicon dioxide. Matéria (Rio de Janeiro), [online] 30, p.e20240858. https://doi.org/10.1590/1517-7076-RMAT-2024-0858.

Ali Zomorodian, S.M., Shabnam, M., Armina, S. and O'Kelly, B.C., 2017. Strength enhancement of clean and kerosene-contaminated sandy lean clay using nanoclay and nanosilica as additives. Applied Clay Science, [online] 140, pp.140–147. https://doi.org/10.1016/J.CLAY.2017.02.004.

Bahmani, S.H., Huat, B.B.K., Asadi, A. and Farzadnia, N., 2014. Stabilization of residual soil using SiO2 nanoparticles and cement. Construction and Building Materials, [online] 64, pp.350–359. https://doi.org/10.1016/J.CONBUILDMAT.2014.04.086.

Changizi, F. and Haddad, A., 2017. Improving the geotechnical properties of soft clay with nano-silica particles. Proceedings of the Institution of Civil Engineers: Ground Improvement, [online] 170(2), pp.62–71. https://doi.org/10.1680/JGRIM.15.00026;WGROUP:STRING:PUBLICATION.

Jansen, R.B., 1988. Advanced dam engineering for design, construction, and rehabilitation. Advanced dam engineering for design, construction, and rehabilitation. https://doi.org/10.1007/978-1-4613-0857-7/COVER.

Kalhor, A., Ghazavi, M., Roustaei, M. and Mirhosseini, S.M., 2019. Influence of nano-SiO2 on geotechnical properties of fine soils subjected to freeze-thaw cycles. Cold Regions Science and Technology, [online] 161, pp.129–136. https://doi.org/10.1016/J.COLDREGIONS.2019.03.011.

Lo, A.-Y., Wang, C., Hung, W.H., Zheng, A. and Sen, B., 2015. Editorial Nano-and Biomaterials for Sustainable Development. [online] https://doi.org/10.1155/2015/129894.

Masrour, F.F., Mirsadeghi, M.N., MolaAbasi, H. and Chenari, R.J., 2021. Effect of Nanosilica on the Macro- and Microbehavior of Dispersive Clays. Journal of Materials in Civil Engineering, [online] 33(12), p.04021349. https://doi.org/10.1061/(ASCE)MT.1943-5533.0003975.

Sherard, J.L., Dunnigan, L.P. and Decker, R.S., 1976. Identification and Nature of Dispersive Soils. Journal of the Geotechnical Engineering Division, [online] 102(4), pp.287–301. https://doi.org/10.1061/AJGEB6.0000256.

Vakili, A.H., Kaedi, M., Mokhberi, M., Selamat, M.R. bin and Salimi, M., 2018. Treatment of highly dispersive clay by lignosulfonate addition and electroosmosis application. Applied Clay Science, [online] 152, pp.1–8. https://doi.org/10.1016/J.CLAY.2017.11.039