Proceedings of the Seventeenth International Conference on
Civil, Structural and Environmental Engineering Computing
Edited by: P. Iványi, J. Kruis and B.H.V. Topping
Civil-Comp Conferences, Volume 6, Paper 12.5
Civil-Comp Press, Edinburgh, United Kingdom, 2023
doi: 10.4203/ccc.6.12.5

Nano Soil-Improvement or Nano Ground-Improvement in Geotechnical Engineering

H. Niroumand[1], L. Balachowski[2] and S. Manafvand Ardi [3]

**[1]Department of Civil Engineering,
Buein Zahra Technical University (IKIU-BZ), Qazvin, Iran
[2]Department of Geotechnical and Hydraulic Engineering,
Faculty of Civil and Environmental Engineering,
Gdansk,University of Technology, Gdansk, Poland
[3]Department of Architecture, Istanbul Technical University,
Istanbul, Turkey**

Abstract

Soil Improvement (SI) plays a very important role as an inevitable matter in many development breakthroughs which have been made in geotechnical Engineering. As a matter of fact, Nanomaterials can be utilized in order to improve the geotechnical properties of soils. Several studies have hitherto been carried out in the field of geotechnical engineering to improve the soil properties by using nanomaterial technique. A variety of investigations have been done using different soil experiments to evaluate the influence of nanomaterials in soil geotechnical properties. In this study, we discussed previous studies on the effect of adding different amounts of various types of Nanomaterials on the geotechnical behavior of soils, their properties and the equipment and experiments used in nanotechnology with the aim of nanotechnology advancement in geotechnical engineering. All result showed that adding Nanomaterial to soils enhanced their physical and mechanical properties. Nano Soil-Improvement (NSI) or Nano Ground-Improvement (NGI) varies according to the type, quality, Nano-ratio added, and the characteristics of the natural soil. As a result, a new classification was introduced and the significant effects of nanomaterials on the soil properties were evaluated.

Keywords: nano ground-improvement, nano soil-improvement, soil improvement, nanotechnology, geotechnical engineering

1 Introduction

The ideas and concepts of nanoscience and nanotechnology began in December 1959 at a meeting of the American Physical Society at the California Institute of Technology, when physicist Richard Feynman gave a presentation titled "There's So Much Space Below" [22]. From the scientific and environmental point of view, nanomaterials have some beneficial properties that can be economically friendly and improve the quality of products, but these unique effects of nanotechnology have not been introduced in geotechnical engineering [1, 2]. Many facts are left behind in geotechnical engineering due to insufficient research at the nanoscale. This is because most soil and rock minerals are on the nanoscale, and their chemical reactions occur at the nanoscale. It can be said that nanotechnology has an excellent potential for use in soil improvement, soil stabilization, etc. [2]. Previous academic researchers have indicated that adding nanomaterials to soil enhances its physical and mechanical properties. Soil improvement varies according to the type, quality, nano-ratio added, and characteristics of the natural soil. So, a new classification was made, and the major effects of nanomaterials on the properties of soil were looked at.

Nano is a scale unit; the word nano is derived from the Greek word nano (in Latin nanus), and it means dwarf [10]. Nanotechnology is deemed capable of setting in motion a new industrial evolution, thanks to the possibility of manipulating materials on a nanometric scale [17]. Nanotechnology is a branch of science that is understood as the control and restructuring of matter at the nanometer (nm) scale, using particles smaller than 100 nm (1 nm = 10-9) to create materials and objects with new properties and functions [7, 16]. Nanotechnology can develop and create materials that perform better and behave differently compared to existing materials. For example, objects can change color and shape much more easily, and basic properties such as resistance, surface-to-mass ratio, conductivity, and flexibility can be increased [17]. The possibilities offered by nanotechnology cover a wide variety of fields, from electronics to medicine, from energy to aeronautics, to name a few; one of them is the construction industry, which is considered a promising field of application of nanotechnology [17]. Nanotechnology represents an example of how innovation increasingly combines dematerialization, eco-efficiency, and a knowledge-based approach to develop new products in the building materials fields [11].

2 Methods

2.1 Nanotechnology in Geotechnical Engineering

Modern geotechnical engineering develops new materials to achieve a more stable soil composition, raise the soil's compressive strength, and improve the soil's durability. The nanotechnology technique can be used to perform nanoscale monitoring and investigation of soil and rock masses. Not only may it be used to acquire a more precise understanding of the mineralogy and morphology of the soil, but it can also be utilized to determine the soil's chemical and physical properties. In addition, alteration of the soil and rock structure at the molecular or atomic level is made possible.

2.2 Soil Types

In geotechnical engineering, soil is an accumulation of un-cemented or weakly cemented mineral particles with sizes ranging from less than 1 nm to 75 mm [3, 4]. Four soil types are generally recognized in classical geoengineering, these are gravel, sand, silt, and clay; dimensions are given in Table 1 [21].

Particle	Lower limit	Upper limit	Ratio
Gravel	4.75 mm	75 mm	15.8
sand	0.075 mm	4.75 mm	63.3
silt	2 μm	75 μm	37.5
Clay (classical)	1 nm	2 μm	2000
Clay (proposed)	0.1 μm	2 μm	20
Nano Particle	1 nm	100 nm	100

Table 1: dimensions of soil types in classical geoengineering

2.3 Soil Improvement

Existing soil on a building site may not always be ideal for structural support. According to [12], various soil improvement strategies are employed, such as:

1. Reducing the settlement of structures,
2. Increasing the bearing capacity of shallow foundations by enhancing the soil's shear strength,
3. Increasing the factor of safety against the potential slope failure of embankments and earth dams.
4. Reduce the soil's shrinkage and swelling.

In its broadest sense, soil improvement refers to modifying any soil property to enhance its engineering performance. This could either be a short-term procedure to approve the building of a facility, or the performance of the finished facility may be permanently enhanced by soil improvement techniques. A technique's application might lead to improved groundwater quality, increased strength, or both [12].
As [12] stated, the different ways to improve soil are:

1. Compacting the surface,
2. Ways to drain water,
3. Methods of Vibration,
4. Recompression and consolidation,
5. Chemical Stabilization,
6. Soil Reinforcement.

The scope of application of the various techniques mainly depends on the type and degree of soil that needs improvement.

2.4 Soil Improvement and Nanotechnology

Soil improvement is a traditional strategy used to enhance soils to fulfill the specifications of different kinds of projects [1]. Traditionally, materials such as cement and mineral additives such as fly ash, silica fume, and rice husk ash were used for improving soils [1].

Soil and rock minerals contain nanomaterials such as Halloysite, Sepiolite, Hematite, Allophane, Smectite, Imogolite, Palygorskite, and Goethite . Due to the fact that soil particles containing organic matter and clay minerals have a very high specific surface area, nanoparticles can influence the soil's physical and chemical properties as well as its microstructure [1].

Due to the complex physical and chemical properties of soil, predicting its behavior is very difficult. With nanotechnology, we can predict its behavior. In addition, nanoparticles can affect soil properties even in tiny fractions, and it was found that nanoparticles can appear to have voids in nanoparticles, which can lead to an increase in the specific surface area, thereby increasing the soil's water retention and the absorption of organic matter, which reduces the bulk density [21].

Nanoscale zerovalent iron (nZVI), titanium dioxide (TiO2), zinc oxide (ZnO), multiwalled carbon nanotubes (MWCNTs), fullerenes, bimetallic nanoparticles, and stabilized nanoparticles are the nanoparticles most commonly utilized for soil improvement [6, 9]. Due to their size and properties, nanomaterials have vastly increased surface areas and sorption sites, making them excellent absorbents [6, 9]. A research investigated the impact of natural nanoparticles on the soil's engineering properties. He discovered that even trace amounts of nanoparticles in soil have a significant impact on its physical, chemical, and engineering properties. [21]. A few researchers conducted a study on the plasticity and strength properties of fine soil and its nanomaterial-containing mixture. [5]. The results demonstrated that the addition of Modified Montmorillonite Nano clay to soil increases the liquid limit and plasticity index and significantly improves the soil's unconfined compressive strength. Studies show that the use of nanomaterials in the field of chemical reactions is more effective than their physical presence in the soil structure, which is important for making weak soils stronger. [1].

3 Results

3.1 Effect of Nanoparticles on Coarse Grained Soil

3.1.1 Colloidal Silica

When 32 wt. % colloidal silica was added to coarse-grained soil, it was said that 335 KPa of unconfined compressive strength was reached. [19]. It was found that adding silica to sand grout made the compressive strength higher. When the amount of silica was upped to 27%, the compressive strength reached 400KPa after 7 days. [1].

Tri-axial tests were also done on the sand, and it was found that the sand was better able to resist forces in the form of structural weight when Nano-material was used. It was found that when 4.5 wt.% colloidal silica was added to the specimen with a relative density of 45%, the liquefaction resistance was the same as that of the untreated specimen with a relative density of 75% or more. [18].

3.2 Nano clay

When Nano-clay was used in the soil, plastic and liquid limit was calculated, and it was found that significant improvement was seen. When 1 wt.% of Nano clay was added than increment of 13% and 38% was seen in liquid limit and plastic limit respectively which in turn justifies that plasticity index was decreased by 40% . [14]. Studies indicated that when 2% to 4% Nano-clay was added, then compressive strength of soft soil was increased from 3% to 22%. [8].

3.3 Effect of Nanoparticles on Fine Grained Soil

3.3.1 Nano Alumina

It was determined that the unconfined compressive strength of the specimen treated with 1% nanoscale aluminum oxide was 4,2 times greater than that of the untreated specimen when nanoscale aluminum oxide was added to cohesive soil containing sewage sludge cement with a cement-to-sludge ash ratio of 1:3. [8].

3.3.2 Nano Clay

A few researchers stated that when Nano clay was utilized in the silt stabilization (classified as MH and ML), the unconfined compressive strength test (UCS) and the California bearing ratio test (CBR) were conducted to determine the strength. [8]. Nano clay was used at 0.5, 1, 1.5, and 2 wt.%, and it was discovered that the CBR value of untreated specimens was 5 and 8 for MH and ML, and that the CBR value increased by 68.75% and 77.7% when Nano clay was added at 1.5 and 1 wt.%.

When 0.1, 0.2, and 0.3 wt.% Nano clay was used as an additive, the geotechnical properties of soft soil changed, as the plastic limit and liquid limit of soft soil decreased along with the plasticity index of soil, whereas the maximum dry density of soil increased. [15].

3.3.3 Nano silica

When Nano silica was used alone in clay, there was no significant increase in compressive strength; however, when lime was added to Nano silica, the compressive strength of clay rose. [1, 13]. According to a study conducted by [13], the result of the activation of the pozzolonic reaction by lime present in the sample, a significant increase in compressive strength was observed. At 90 days, the maximum compressive strength value of 45 KPa was attained when 3% lime and 3% Nano silica were employed, and it was fascinating to observe that the compressive strength grew gradually with the rise in curing age [1, 13].

4 Conclusions

This paper investigates the effect of adding different amounts of various types of Nanomaterials on the geotechnical behavior of soils, their properties, the equipment, and experiments used in nanotechnology. All results showed that adding

Nanomaterial to soils enhanced their physical and mechanical properties. This paper indicates that the improvement in geotechnical engineering by employing nanotechnology to reinforce and provide appropriate strength to the soil provides it to perform better so that construction can be done on these types of soil. It was found that the addition of nanoparticles to the soil raised the compressive strength of the soil significantly, lowered the liquefaction of the soil to a certain amount, and decreased the settling of the soil as the resistance of the soil to compression increased.

Acknowledgements

The authors acknowledge the financing of the Polish National Agency for Academic Exchange.

References

[1] Arora, A., Singh, B. and Kaur, P., "Performance of Nano-particles in stabilization of soil: A comprehensive review", Materials Today: Proceedings, Elsevier Ltd., Vol. 17, pp. 124–130, 2019.

[2] Booker,R. and Boysen, E., "Nanotechnology for Dummies", Wiley Publishing, 384, 2005.

[3] Craig, R.F., "Craig's Soil Mechanics", Taylor & Francis Group, 7th ed. 2004.

[4] Ghasabkolaei, N., Janalizadeh Choobbasti, A., Roshan, N. and Ghasemi, S.E., "Geotechnical properties of the soils modified with nanomaterials: A comprehensive review", Archives of Civil and Mechanical Engineering, Vol. 17 No. 3, pp. 639–650, 2017.

[5] Ghazi H., Baziar M.H., Mirkazemi S.M., "The effects of nano-material additives on the basic properties of soil", 14th Asian regional conference of geotechnic, Hong-Kong, 2017.

[6] Gong, X., Huang, D., Liu, Y., Peng, Z., Zeng, G., Xu, P., et al., "Remediation of contaminated soils by biotechnology with nanomaterials: Bio-behavior, applications, and perspectives", Critical Reviews in Biotechnology, Vol. 38 No.3, pp. 455–468, 2018.

[7] Hernández-Moreno, S. and Solache de la Torre, S.C., "Nano-Technological Products in Architecture and Construction", Holos, Vol. 2, pp. 35-51, 2017.

[8] Khalid, N., Arshad, M.F., Mukri, M., Mohamad, K., Kamarudin, F., "Influence of Nano-Soil Particles in Soft Soil Stabilization", EJGE, Vol. 20, pp. 731-738, 2015.

[9] Khin, M.M., Nair, A.S., Babu, V.J., Murugan, R., and Ramakrishna, S., "A review on nanomaterials for environmental remediation", Energy & Environmental Science, Vol. 5, pp. 8075–8109, 2012.

[10] Leydecker, S., "Nano Materials in architecture, Interior architecture and Design", Springer Science & Business Media, Birkhäuser, Berlin, Germany, 2008.

[11] Lou, H.L., Hsiao, D.H. Lin, C.K., "Cohesive soil stabilized using sewage sludge ash/cement and nano aluminum oxide", International Journal of Transportation Science and Technology, Vol. 1 No. 1, pp. 83–100, 2012.

[12] Mahdia, B., Majeed, Z., Hussein, S., Abbas, Z., Hamood, H., "Application of Nanotechnology in Geotechnical Engineering: A review", Saudi Journal of Engineering and Technology, Vol. 6 No. 6, pp. 143-151, 2021.

[13] Majeed, Z.H., Taha, M.R., "Effect of nanomaterial treatment on geotechnical properties of a Penang soft soil", Asian Scientific Research, Vol. 2 No. 11, pp. 587–592, 2012.

[14] Mohamadzadeh Sani, A., Arabani, M., Haghi, A.K. Chenari, R.J., "Effect of nanoclay additive on the geotechnical properties of silty sands", 4th International Conference on Geotechnical Engineering and Soil Mechanics, Tehran, 2010.

[15] Nikookar, M., Bahari, M., Nikookar, H., Arabani, M., "The strength characteristics of silty soil stabilized using nanoclay", 7th Symposium on Advances in Science & Technology (7thsastech), Bandar-Abbas, Iran, 2013.

[16] NSTC USA. "The National Nanotechnology Initiative– Strategic Plan", December 2007, Executive Office of the President of the United States, 2007.

[17] Scalisi, F., "Nano-materials for Architecture", Journal of Civil Engineering and Architecture, 1061-1067, 2017.

[18] Towhata, I., Kabashima, Y., "Mitigation of seismically-induced deformation of loose sandy foundation by uniform permeation grouting", Earthquake Geotechnical Engineering Satellite Conference, XVth International Conference on Soil Mechanics and Geotechnical Engineering, Istanbul, Turkey, pp. 313–318, 2001.

[19] Yonekura, R., Miwa, M., "Fundamental properties of sodium silicate-based grout", The Eleventh Southeast Asia Geotechnical Conference, Singapore, pp. 439–444, 1993.

[20] Zhang, G., "Soil Nanoparticles and their Influence on Engineering Properties of Soils", Geotechnical Special Publication, Conference: Geo-Denver, pp. 1-13, 2007.

[21] Zhang, G., "Soil nanoparticles and their influence on engineering properties of soils", Advanced in measurement and modelling of soil behaviour, Geo-Denver, ASCE, 2007.

[22] Zheng, X., "Applications of Nanotechnology in Geotechnical Engineering", Arizona State University, Ph.D Thesis, December, p. 112, 2016.