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Improvement on Strength Characteristics of Soil Using Nanomaterials: A Critical Review

Jayanti Munda[1] and Supriya Mohanty[1]

[1]Department of Civil Engineering, Indian Institute of Technology (BHU), Varanasi, Uttar Pradesh, 221005, India
jayantimunda.rs.civ19@itbhu.ac.in

Abstract. In the recent development of advanced technologies, nanotechnology can be used in the field of geotechnical engineering to improve the strength of the soil. Nanomaterials are the smallest particles found in the soil environment and their sizes ranges between 1nm and 100nm. This paper presents a critical review on soil stabilization and its influence on soil properties when mixed with different types of nanomaterials like nano silica, colloidal silica, nano clay, nano copper, nano alumina etc. In the present study, it has been observed that very small amount of nano material influenced the geotechnical characteristics of soil. Various laboratory tests such as consistency limits, compaction characteristics, unconfined compressive strength (UCS), hydraulic conductivity, California bearing ratio (CBR) tests were performed on soil mixed with different types of nano materials. The unconfined compressive strength and CBR results increases with increase in nano material upto a certain limit and then decreases afterwards and permeability decreases with increase in nanomaterial. Many chemical analysis tests were performed to study the microstructure of soil stabilized with nano materials.

Keywords: soil stabilization, nonmaterial, consistency limits, UCS, CBR.

1 Introduction

Soil is mostly used naturally available materials in the discipline of Civil engineering. Various type of Civil engineering structures are generally constructed on soil. With the passage of time there is a scarcity of building sites and thus drastically increase of undesirable sites due to the problematic soil. Soil stabilization is used as traditional approach for soil treatment by adding different types of additives like fly ash, lime, cement etc. In the recent developments of Nanotechnology and Science and the availability of several new materials have developed for soil improvement. Nanomaterials can perform better results compared with other additives at micro or larger scales because of its huge specific surface area and surface charges. Nanotechnology was first introduced in a lecture entitled "There is plenty of room at the bottom" by the American physicist, Richard Feynman in 1959 at the California Institute of Technology [1]. It encouraged others into new findings in the area of nanotechnology. The nanotechnology can be defined in different ways that usually interconnected. The nanotechnology can be described as, "The science with synthesis, characterization

and application of different types materials that identified in the nanometer range". Nanomaterials, which define the size of the structures with at least one dimension, ranged between 1nm to 100nm.
This paper reviewed on the developments of Nanotechnology in the area of geotechnical engineering and their applications for soil improvement. The performances of different types of nanomaterials have been studied.

2 Nanomaterials in Soil Strength Improvement

Nanoparticles react very actively with soil by considering their large specific surface area and surface charges and hence exhibit better performance on the microstructure, physical, chemical and engineering properties of soil. As soils are natural materials that possess complex behavior, sometimes it is difficult for predicting the behavior and thus it is challenging. With the evolution of Nanotechnology, various types of nanomaterials are accepted to modify the geotechnical properties of soil, which is more effective and economical. In the present paper there are five types of nanomaterials are reviewed for soil improvement: Nano Silica, Nano Clay, Colloidal Silica, Nano Alumina and Nano copper.

2.1 Nano silica

Nano Silica (NS) is a white powder that is composed of large purity of amorphous silica powder. Due to its very small size of particles, nano-SiO2 has advantages of high specific surface area, good surface adsorption and high surface charges.When Nano-SiO2 was added with various percentages of 0.5, 0.7 and 1 % by weight of the clayey soil. The results obtained that with increment in NS content, shear strength parameters, unconfined compressive strength and maximum dry unit weight of soil increased. The optimum value obtained at 0.7% on the shear strength parameters [2]. Similarly,with the developments in science and technology, when Nano-SiO2 was added with kaolinite in various percentages (1-5%) by weight of soil. It was found that unconfined compressive strength can increase by 1.43 times to that of the parent soil and the optimum value of NS content obtained at 4% [3]. With the inclusion of nano silica to the polyvinyl alcohol fiber, which is reinforced to the cemented sandy soil, there was an increment of energy absorption capacity. NS upto 8% increases the ultrasonic pulse velocity [4]. Further the effect of nano silica by conducting static and cyclic triaxial tests were performed on the cemented sand. The optimum amount of NS was 10% by dry weight of cement [5].The effect of clayey soil was studied by mixed with various percentages of Nano silica i.e. 5, 10, 15 and 20% by weight of soil. It was found that UCS of clayey soil increased with each increment of nano silica content [6]. Various types geotechnical experiments were conducted to analyses the performance of two different sizes 15nm and 80nm of nano silica on cemented residual soil. It was found that 15nm size nanoparticles obtained better result in strengthening the soil than 80nm nanoparticles and achieved larger compressive strength of cemented soil with 0.4% NS and 8% cement was 85% higher than soil treated with 8% cement [7].

2.2 Colloidal silica

Colloidal silica (CS) products are suspensions of fine amorphous, nonporous and spherical particles of silica. Various cyclic triaxial tests were conducted on the loose sand stabilized at different concentrations of colloidal silica i.e. 5, 10, 15 and 20%. The test results obtained that during cyclic loading CS grout at higher concentrations, there was considerable development of deformation resistance in case of loose sand [8]. The influence on transport of CS through the soil formations were investigated by short column (0.9m) tests. An unconfined compression test shows that 5% silica was adequate to mitigate liquefaction risk [9]. The centrifuge modelling was used for the treatment of loose liquefiable sand mix with colloidal silica. It was found that the settlements of stabilized loose sand were 25 times less compared to the unstabilized sand [10]. A simple cyclic shear tests were performed on the liquefiable silty sand mixed with colloidal silica grout. It was found that on cyclic loading CS grout reduced the generation of pore pressure [11]. The centrifuge model tests were performed on the untreated and treated liquefiable sand mixed with colloidal silica of different concentrations of 4, 5 and 9% by weight. With each increment in concentration levels of colloidal silica, it produced higher cyclic resistance ratios and the lesser cyclic shear strains [12]. When colloidal silica mixed with silty sand and then increased the concentrations upto 10%, which have a less development on the drained shear strength parameters(c,φ) of soil. However, by increasing CS from 10-30%, under drained condition, the cohesion of treated soil significantly increased and the angle of internal friction decreased [13].

2.3 Nano clay

Nano clays (NC) are layered mineral silicates of nanoparticles. Nano clays are classified into different groups namely, montmorillonite, bentonite, kaolinite, hectorite, and halloysite that are categorized based on their chemical configuration and nanoparticle structure. The maximum unconfined compressive strength of the silty soil with low plasticity (CL-ML) reinforced with randomly oriented polypropylene fibres mixed in the presence of nano clay is much higher than the soil reinforced with the fibres in the absence of nano clay [14]. The pinhole tests evaluated the dispersivity potential of dispersive clayey soil. By the addition of nano clay, it decreases the dispersivity potential of the dispersive clayey soils [15]. When nano clay was mixed in the compacted clayey sand of an earth dam, it decreased the hydraulic conductivity. The optimum content of nano clay was obtained at 3%. At the optimum content of nano clay, it substantially decreased the hydraulic conductivity. On the other hand, the shear strength increased on drained condition, but decreased on undrained condition [16].

2.4 Nano alumina

Nano Alumina (NA) occurs in the form of spherical and they appear as white powder. They are found in the form of oriented and undirected fibers. For improvement of soft soil strength, 15% of clayey soil sample was substituted with sewage sludge ash (SSA) and cement ratio to develop the stabilized soil samples and then different volumes of nano alumina i.e. 0, 1, 2 and 3% were mixed with the stabilized soil. It was found that 1% of nano alumina gives the optimum result and 15% of SSA/cement replacements effectively stabilize the clayey soil sample [17]. The durability and micro structure of cement mortar was investigated using nano alumina by performing water absorption, electrical resistivity and scanning electron microscope. The amount of cement in the mortar was replaced with 1, 3 and 5% of NA by weight of cement. The results showed that the highest value of electrical resistivity obtained with 5% NA and little variations in the water absorption with maximum value of 8.5% for 5% NA [18].

2.5 Nano copper

The morphology of copper nanoparticles is round and they appear as a brown to black power. The amount of expansion and shrinkage strains were measured in residual soil mixed with three types of nano materials namely nano clay, nano copper and nano alumina. The residual soil modified with nano copper was greater significant improvement compared to the nano alumina in the volumetric expansion and shrinkage strain, as the density of nano copper is much higher than nano alumina that leads to increase in specific gravity of the composite and hence increases the maximum dry density of the composite material [19]. The collapsible soil samples were treated with four types of nano materials with various percentages 0.1, 0.2, 0.4 and 0.6% (nano clay, nano copper, nano alumina and nano silica) to determine the collapse potential of the soil. The combination of four types of nano materials with the soil in terms of colloid solutions gives the better results in reduction of collapse potential [20].

3 Conclusions

This paper investigated the performance and implementation of nanotechnology in the discipline of Civil engineering. There are various type of nano materials, including nano clay, nano silica, colloidal silica, nano alumina and nano copper are considered for problematic soil improvement and their effectiveness were verified by conducting various geotechnical experimental studies. The nano materials have excellent properties due to their very high specific surface areas and reactive surface charges. Thus, it reacts very strongly with other particles in the soil composite. Therefore, the advantages of nano materials exhibit significant improvement in the geotechnical characteristics of soil. Addition of nano materials in the soil increases the shear strength, unconfined compressive strength, consolidation characteristics and California bearing ratio as well as decreases the hydraulic conductivity and liquefaction potential.

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