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Investigation of nano-silica effects on Coarse-grained soil's compressive strength: A case study for Aras Free Trade Zone (AFTZ)

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ABSTRACT

Based on the increasing the usage of the resources and population growth, the soil with suitable properties for civil engineering project such as pavement construction is not available. Therefore, it is obligatory that the enhancement of local soils properties should be appropriately deliberated. If for some reason it is not possible to relocate the project and replace the soil, or if the cost of soil replacement is not cost-effective, the soil remediation method should be considered so that if this method is economically and technically justifiable, it should be done. From this perspective, the effects of Nano-silica on soil compressive strength are important and necessary. In this study, a specific and different number of samples are prepared for comparison. The purpose of this study is to measure the uniaxial compressive strength of granular soils. It was concluded that Nano-silica filled pore space between Sand particles and a dense matrix were formed. This textural event caused an improvement in compressive strength of stabilized soils In this regard, the use of Nano-silica as a suitable and efficient additive in the thickening processes is recommended.

1. Introduction

Nanotechnology is a new emerging trend in the field of soil mechanics, and many experimental investigations are still going on to reveal its applicability in improving the soil properties. Unfortunately, the usefulness of nano-materials in the field of ground improvement is still not been recognized completely. The first hint about the concept of particles on a small scale was introduced by Richard Feynman which while delivering a seminar at the yearly meeting of the American Physical Society at Caltech in 1959. The talk revealed the importance of decreasing the particle size to get more information about the object and explained it with different cases that were relevant at that time because that was the first time in history one could explain the concept of Technology in nano-scale (Feynman, 1960). Due to the smaller size of particles, the specific surface area of the nano-particles is more, so a small percentage of nano-particle in the soil can give rise to in a sizeable enhancement in physical and chemical features of the soil in microstructural level (Shahin et al., 2017). In general, determining and predicting the mechanical condition of soil or any soil structure is very important in civil engineering. In order to do this correctly, it is necessary to use the correct parameters of material strength, correct selection of practical tests, natural and industrial additives and software according to the need for the behavior of the structure that can be a logical result to determine soil behavior (Babu and Joseph, 2016).

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Soil improvements are generally classified into two processes, soil modification or soil stabilization. “Modification” involves changing the texture and moisture sensitivity of the soil, usually by a change in the soil’s plasticity. “Stabilization” refers to a long-term strength gain of the compacted soil, which may occur in addition to the modification (Parsons et al., 2001; Indot, 2015) Received. In industrialized countries producing silica sand, this material is usually used to stabilize the materials of the underlying layers of rigid pavements. Because if soils and materials that are stabilized only with silica sand are exposed to frequent freezing and thawing or changes in humidity, their strength and durability are greatly reduced and crushed. If silica sand with lime is used to stabilize the soil and sandy surfaces, it is necessary to cover it with a protective asphalt layer after stabilizing the soil to prevent the erosion of the stabilized soil. Silica sand can be used to stabilize soils with different characteristics and granulations, but soils that contain large amounts of carbonaceous organic matter are by no means suitable for silica sand stabilization (Changizi and Haddad, 2016).

In general, the use of silica sand is more suitable for stabilizing fine-grained soils compared to coarse-grained soils (Barzgarbfrui et al., 2015). The durability of fine-grained silica-based fine-grained soils is higher than that of coarse-grained soils, while the initial strength of coarse-grained silica-based fine-grained soils is higher than that of fine-grained soils. The percentage of silica sand as well as lime used for soil stabilization, in addition to soil granulation, depends on the surface texture of the grains, rock materials and the type of silica sand (Gallagher et al., 2007).

Regarding nano-silica, it should be mentioned that the researchers of Isatis nano-silica industrial company of Yazd, by acquiring the technology of producing nano-silica gel and powder, succeeded in the industrial production of this material with wide applications in the construction and rubber industries. Nano-silica consists of a set of small SiO_2 particles that are bonded together by chemical bonds to form larger particles. The main advantage of nano-silica compared to silica is the high surface area of this material, which causes it to show more interaction in the substrate used. Nano-silica has a variety of applications, including in the paint industry as a matte, concentration enhancer and enhancer of environmental resistance and abrasion properties (Delnavaz, and Jalilavand, 2015).

Nano-silica is completely transparent and can be used in transparent coatings. Nano-silica can also be used in the rubber industry as a filler and increase the strength and durability of rubber. In addition to eliminating the environmental problems of soot, this replacement reduces energy consumption for movement and the amount of noise caused by movement. Nano-silica in concrete structures and cementitious compounds increases the environmental strength of the final concrete (Ghasemi Panah et al., 2018).

The use of this material also improves the abrasion properties and strength of the composition along with reducing the permeability and reducing the dry volume of cement. This nano-silica gel and powder is produced on an industrial scale for the first time in the country. At present, the production capacity of nano-silica gel and powder is 200 tons per year, which can be increased to 3,000 tons per year. Meanwhile, the rubber, paint and cement industries currently need 5,000 tons of this powder per year, which is met through imports from European countries. The price of a foreign sample of gel is 3$ per kilogram and the foreign sample of powder is 11$, and the domestic sample is offered at a quarter of the price of a similar foreign sample (Gallagher et al., 2007).

2. Material and Methods

2.1. Research method

To perform the test, the dimensions and weight of the sample are measured according to the standard and placed in the loading device on the lower plate and the upper plate is contacted without applying load on the surface of the sample. The displacement gauge becomes zero in this condition. Loading is performed at a speed that achieves 0.5 to 2% of the axial strain per minute so that the time required for the rupture of the sample is about 15 minutes. The test is stopped when the specimen is ruptured (Huang and Wang, 2016).

The test results are displayed as a stress-strain diagram and the amount of uniaxial compressive strength of the soil is determined. Compressive strength parameter, percentage of additives of nano-silica materials and granular and cohesive soil samples are the variables studied in this research. The study is also laboratory and its introductory parts are library. In this study, a specific and different number of samples are prepared for comparison.

The purpose of test is performed with ASTM D2166-85 which is to measure the uniaxial compressive strength of intact or intact adhesive soils using the controlled stress method. With the help of this test, the approximate and fast determination of the uniaxial compressive strength of the soil, which has sufficient and suitable adhesion for this test, is determined approximately and quickly. The data that are extracted from the laboratory, after analysis and analysis by software such as Excel, are presented in the form of graphs and tables, and the presentation of relationships and coefficients is on the agenda (Zamani and Saba, 2010).

In sandy soils with high groundwater levels, during earthquakes or other abnormal ground movements, the possibility of a lack of ground resistance due to increased water pressure is very high. Soils that lose their shear strength act like a thick liquid. During an earthquake, the earth appears to be flowing and boiling sand. The main reason for this phenomenon can be expressed as the soil undergoes cyclic shear deformations, which increases the pressure of pore water and thus reduces the effective stress. After earthquakes similar to Niigata and Alaska, which caused significant and similar damage to buildings, embankments and natural slopes, more attention was paid by researchers to a detailed study of the phenomenon of soil flow. Despite good compressive strength, soil has poor tensile performance and poor performance (Mitchell and Soga, 2005). To compensate for this weakness, they often use various reinforcements in earthen structures. For example, the use of synthetic fibers in road construction has received much attention in recent years due to its desirable strength properties for the intended applications. Among these synthetic fibers are polypropylenes. Polypropylenes are new polymeric materials, some of which are used in soil reinforcement. The use of such synthetic fibers in the base layer of roads leads to an increase in their carrying capacity. Unplanned roads are usually used for low traffic and as access roads (Butron et al., 2009).

The mechanical properties of most soils change with increasing moisture and saturation, and this phenomenon is known to geotechnical engineers, but in some soils due to increasing moisture, special phenomena occur that sometimes lead to major damage in construction projects. These soils can be called water sensitive soils. Some types of these soils are: swollen soils, divergent soils and compacted soils, liquefied soils, soluble soils, unstable sandy soils, organic and loamy soils (Soroush and Aghaei, 2010). Unstable sandy soil in terms of aqueous structures refers to soils that in contact with running water are severely and rapidly eroded and are removed from the environment. In terms of general classification, these soils can also be considered as a divergent soil but with a physical nature; due to the erosion and migration of soil particles is done only due to lack of adhesion and fineness of particles. These soils have a relatively limited grain size (Fig. 1) and in terms of Unified classification (USCS) are included, which in common terms SM, SP, fine to medium sand with uniform grain size are generally called wind sand (Karimi et al., 2011).

In addition to granulation and lack of adhesion, these soils generally have low density due to the nature and method of transfer and deposition, and this greatly increases their erosion potential against water flow. As mentioned, liquefaction is a phenomenon that occurs in soils with special characteristics and under special conditions. This phenomenon is most likely to occur in relatively fine non-stick soils, in a state of looseness and saturation, and in conditions of intense vibration movements or shocks. All of the above can be assessed during studies and by performing identification excavations as well as field experiments. In general, relatively fine and loose sandy soils with classification in saturated conditions and high groundwater aquifer have the highest potential of SM or SM-SP, SPT liquefaction in case of severe vibration shocks. To field experiments, some laboratory experiments are used to evaluate the liquefaction potential of soils (Tahouni, 1993). Table 1 is describes the physical properties of the nano-silica used in this study. Also, Table 2 is provided the information about nano-silica particles.

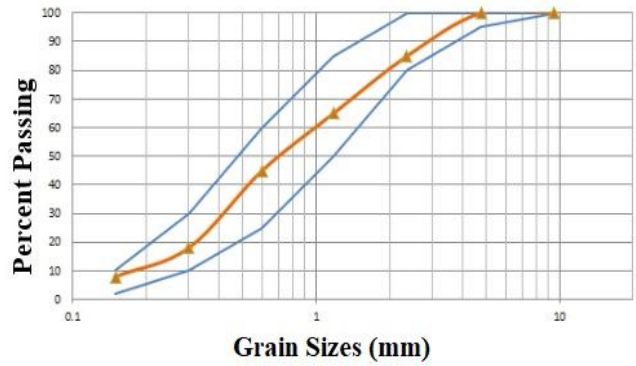

Figure 1. Particle size analysis of the studied soil

Table 1. Physical properties of nano-silica used in the study

Parameter	Unit	Value
Purity percentage	%	99.2
Grain diameter	mm	11 - 13
Specific gravity	m^2/g	40 - 60
Color	-	White
Bulk density	g/m^3	< 0.1
Actual density	g/m^3	2.4

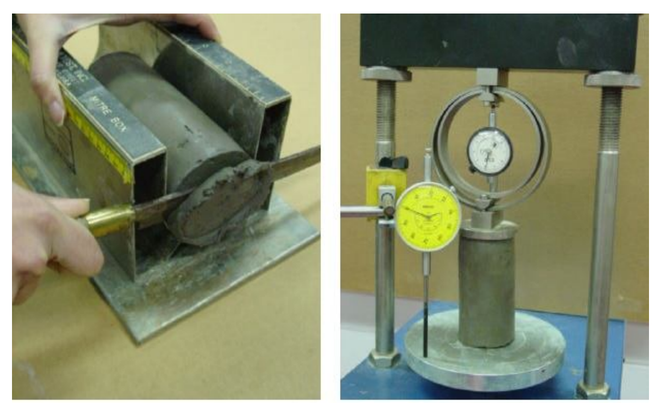

Figure 2. Shattering sample in uniaxial device with the addition of 0.8% nanosilica

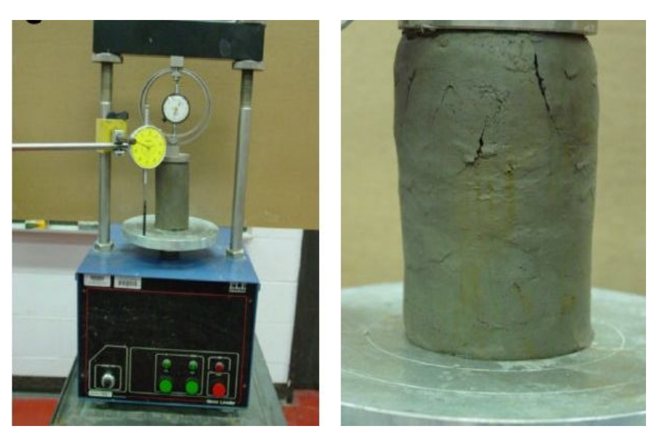

Figure 3. Broken sample in uniaxial device with the addition of 2% Nano-silica

2.2. Uniaxial density test

Drainage uniaxial compaction test in saturated clay soils is one of the most important tests used to determine uniaxial compaction resistance or non-drained adhesion. In the present study, uniaxial density test according to standard (ASTM D2166) on natural and Nano-silica stabilized samples with percentages of 0, 0.2, 0.4, 0.6, 0.8, 1, 2 1/4 and 1.4 were performed immediately after the addition of Nano and with a loading speed of 1 mm / min. In the uniaxial density test, molds with a diameter and height of 4.97 and 10.05 cm, respectively, were used to make the samples. The soil sample prepared under optimal moisture conditions is compacted in 3 layers with almost the same thickness to reach the desired height in a uniaxies (Fig. 2).

3. Results and Discussions

The study of the effects of nano-silica on soil compressive strength is considered very necessary and important because some soils are not suitable for some construction projects due to their undesirable technical properties and are considered unsatisfactory. Such soils sometimes cause many technical and economic problems due to their sensitivity and instability to moisture, low resistance and compaction. If for some reason it is not possible to relocate the project and replace the soil, or if the cost of soil replacement is not cost-effective, the soil remediation method should be considered so that if this method is economically and technically justifiable, it should be done (Fig.3) From this perspective, the effects of nano-silica on soil compressive strength (Table 2) are important and necessary (Iranpour and Haddad, 2016). We see an increase in resistance and then a decrease in resistance. Figs 4 to 6 are provide relevant information about the assessment.

Comparison of three series of compressive strengths for granular soils in different percentages of nano-silica with additive are shows that the optimal percentage of additives for all the mentioned parameters is 2% nano-silica. So, by increasing nano-silica from 0 to 2 %, we see that an increase in resistance and after that decrease in resistance as well as Figs. 7 to 10.

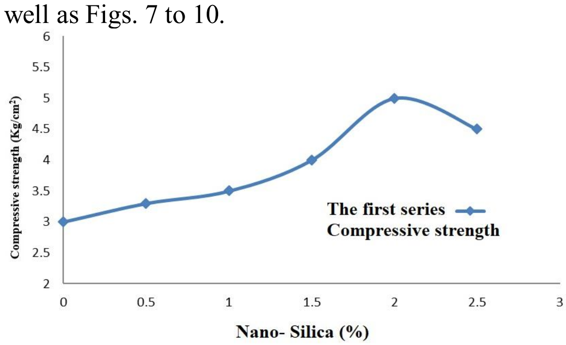

Figure 4. Compressive strength of sandy soil in different percentages of nano-silica additive

Table 2. Results of uniaxial test on nano-silica stabilized soil

Parameters	Variation					
Nano-silica (%)	0.0	0.5	1.0	1.5	2.0	2.5
Uniaxial compressive strength (Kg/cm^2)	3.0	3.2	3.5	3.8	5.0	4.5

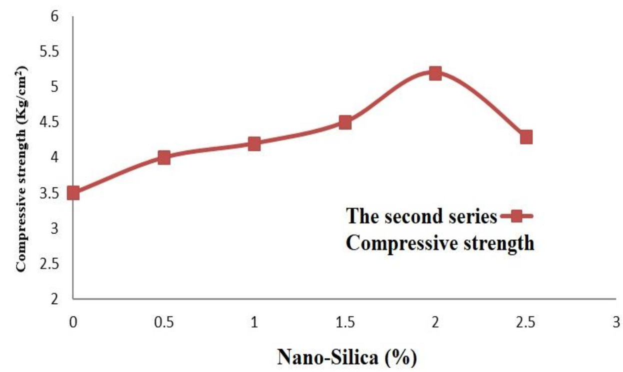

Figure 5. Compressive strength of sandy soils in different percentages of nano-silica additive

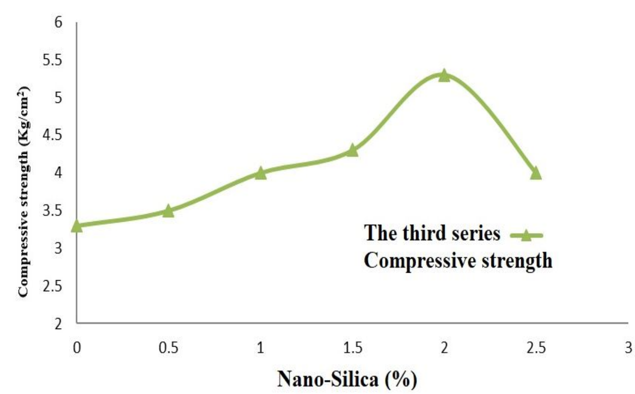

Figure 6. Compressive strength of sandy soils in different percentages of nano-silica additive

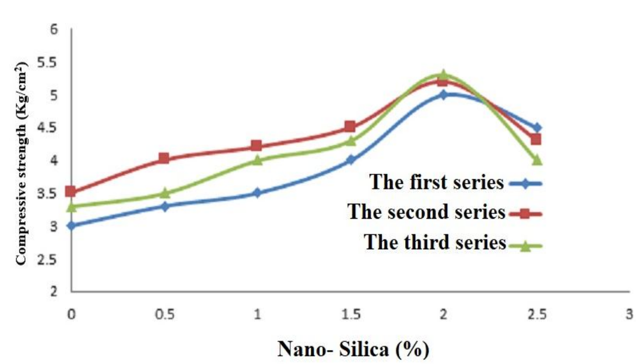

Figure 7. Comparison of three series compressive strengths of sandy soils in different percentages of nano-silica additive

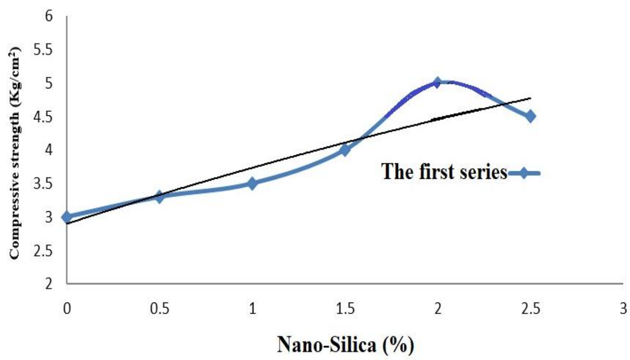

Figure 8. Estimated relationship between nano-silica content and compressive strength of sandy soil

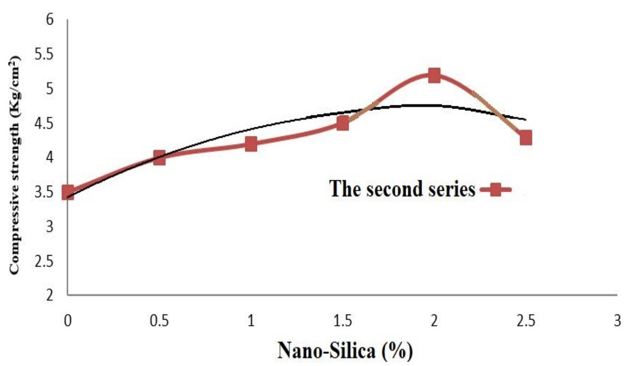

Figure 9. Estimated relationship between nano-silica content and compressive strength of sandy soil

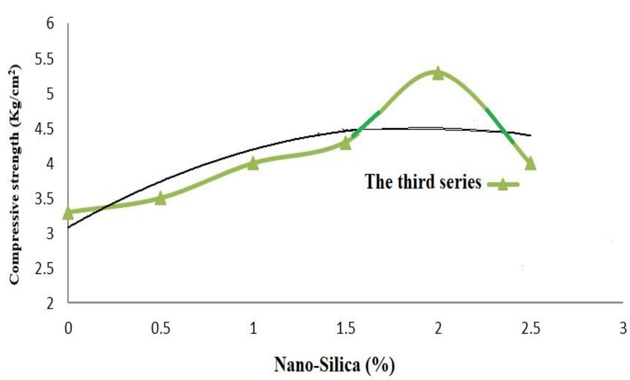

Figure 10. Estimated relationship between nano-silica content and compressive strength of sandy soil

4. Conclusion

In this investigation the effect of nano-silica on mechanical properties of sandy soils were investigated. From this investigation, the following conclusions are made:

A) Nano-silica additive was determined to be about 2% for optimal compressive strength in sandy soil.

B) Comparison of three series of compressive strengths of sandy soils in different percentages of nano-silica additive shows a minimum resistance of about 3.0.

C) Comparison of three series of compressive strengths of sandy soils in different percentages of nano-silica additive shows a maximum strength of about 5.5.

D) The use of nano-silica as a suitable and efficient additive in hardening processes is recommended.

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