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Laboratory Study of the Effect of Clay and Silica Nanoparticles on the Behavior of Silty-Clay Soils in Mashhad

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ABSTRACT: According to the expansion of cities, the necessity of high-rise buildings construction and the need to retrofitting the old buildings is inevitable, particularly in metropolises such as Mashhad with expanded urban areas and neighbor areas of Imam Reza shrine built on the fine-grained deposits, the necessity of improvement and reinforcement of soil is evident. Nanotechnology can be significantly efficient as one of the most useful modern technologies in the recent century to meet the needs of the construction industry. The technology has a significant effect on the improvement of strength and mechanical parameters of soil because of a considerable increase in particle surface. In this regard, this study has investigated the effect of adding clay nanoparticles of type Montmorillonite and Silica of type "S" on the strength and mechanical parameters of silty-clay soils adjacent to Imam Reza's Shrine using laboratory studies. The results showed a significant increase in shear and compressive strength parameters and a decrease in settlement of soil in the Nanosilica-improved samples compared to nanoclay-improved ones. In this way, adding 1% nanosilica and 2.5% nanoclay could cause a 620 and 134% increase in bearing capacity of silty-clay soil, respectively.

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1- Introduction

Mashhad city is located on alluvial deposits of Mashhad plain. The expanded areas of this city, especially the central and eastern areas where the Imam Reza holy shrine is located, have been built on weak and fine-grained deposits. Considering the necessity of high-rise buildings construction such as hotels and commercial complexes in these areas, as well as the need for restructuring in urban decay, soil improvement will be inevitable. Soil improvement and stabilization can increase the bearing capacity of the bed and decrease the precipitation values through increasing shear strength and controlling shrinkage-expansion properties of soil [1]. Over the decades, with the advancement of technology, using nanomaterials in engineering studies has gained the attention of scholars across the world. In nano-scale, the surface to volume ratio and higher cation exchange capacity can lead to an active reaction with other particles and solvents, so that insignificant values of the materials can leave a significant effect on physical and chemical behavior and the engineering properties of soil. Today, to improve the geotechnical properties of soil, the technology is used as a stabilizer [2-4].

Ahmadi and Shafiee (2019) considered the differences in nanosilica and micro-silica properties to investigate the effect of adding the materials on the geotechnical parameters of clay [5]. Tabarsa, et al. (2018) investigated various samples under the impact of improvement with the help of nanoclay in different weight ratios. The results of experiments showed a significant role of nanoclay on the plasticity properties, strength, and deformability of soil [6]. Sui, et al. (2018) studied the shear strength of silty soil by adding carbon fiber and nanosilica by examining direct shear under different overloads. The results showed that the shear strength of soil provided by examined materials has significantly improved its properties [7].

2- Method and Materials

2- 1- Materials

2- 1- 1- Soil

The soil used in this research was picked up from the vicinity around the Razavi holy shrine in Mashhad. Based on the sieve and hydrometer tests this soil was defined as CL-ML. mechanical properties of pure soil were evaluated using the standard tests, and the results are presented in Table 1.

2- 1- 2- Nano-materials

To investigate the effect of nanomaterials on soil mechanical properties, the nanoclay was used in this research is type Montmorillonite - K10 as powder shape and the nanosilica is S-type, as a powdered shape with 99% purity.

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Table 1. Geotechnical properties of studied soil.

Characterizes	Value
G_s	2.64
Maximum Dry Density (□) (kN/m^3)	16.95
Optimum Moisture (□)	15
Liquid Limit (*LL*) (%)	22
Plasticity Index (*PI*) (%)	5
Internal Friction angle (Degree)	25.15
Soil Type	CL-ML

2- 1- 3- Method

Nanoclay and nanosilica independently were mixed with soil in 6 different weight ratios of (0%, 0.1%, 0.5%, 1%, 2.5% and 5%) and (0%, 0.1%, 0.25%, 0.5%, 0.75%, and 1%), respectively. To enhance the precision of laboratory examinations, the results of two samples with the same behavior were used for each weight ratio. The results showed the accuracy of laboratory studies. It should be mentioned that in the case of two similar samples with a different results, the iteration was done until reaching the accuracy of laboratory studies.

3- Results and Discussion

3- 1- The effect of nanomaterials on soil plasticity properties

The results obtained from testing the Atterberg limits show that the nanoclay amount from 0 to 5% of soil weight percentage caused increased liquid, and plasticity limit, and also plasticity index of soil. This is caused by very tiny dimensions and a high specific level of nanoclay. With adding this material to the soil, the contact surface of soil particles was increased and with access to folliculate conditions, water absorption by soil particles, and consequently, the Atterberg limit was increased. On the other hand, the results obtained from the atterberg limit test on improved soil samples with nanosilica showed increased liquid and plasticity properties of soil with an increased percentage of nanosilica and decreased plasticity index of soil.

3- 2- Soil shear strength parameters

According to the effect of nanoparticles on the shear strength of soil, the shear strength of soil in nanoclay and nanosilica-improved samples was significantly increased. The increase was caused by increased internal friction angle and cohesion of particles and soil grains, and as a result, increased the locking and connection among the particles. The internal friction angle in nanoclay-improved soil samples was up to 2.5 weight percent, and the nanosilica-improved samples showed up to 0.75% compared to pure soil at 16 and 22%, respectively. An increase in the said nanoparticles in the studied soil was along with the reverse effect on the internal friction angle of soil. This is caused by an increased level of fine grains and more contact of soil grains as a result of adding nanoparticles to the soil.

Besides, in nanoclay-improved samples, the cohesion level was increased in all weight percentages. The highest level was an 84% increase in soil cohesion improved by 5% nanoclay compared to pure soil. However, the cohesion parameter in Nanosilica-improved samples was increased significantly first, so that by adding 15% nanosilica, cohesion was increased by 108%. Then, this parameter was gradually decreased with an increase in nanosilica percentage. Even the cohesion parameter was decreased in the samples improved by 0.75 and 1 weight percentage compared to pure soil.

3- 3- Soil compressive strength changes

According to the results obtained from the uniaxial test, it could be observed that the optimal value of nanoclay in silty-clay soil is equal to a 2.5 weight percentage. In this weight ratio, the compressive strength of soil was increased by 134% and the strain values were decreased up to 33%. Adding higher values of optimal weight ratio caused decreased compressive strength of soil because of lack of proper distribution of nanoclay particles.

The results of the compressive strength test showed that in the Nanosilica-improved soil samples, the strength was significantly increased compared to pure soil. With adding nanosilica up to 1% of weight, the compressive strength of samples was increased at 620%, and the strain value was decreased by 51%.

4- Conclusion

The results obtained from the study showed that as a result of adding nanoparticles to soil particles, the water absorption, liquid, and plasticity properties of soil were increased because of an increased specific level. The changes are clear in Nanosilica-improved samples. Besides, regarding this study, the soil improvement using nanoparticles did not affect the soil swelling index.

Soil improvement with nanoparticles, along with increased parameters of soil shear strength, was studied. Adding 2.5% nanoclay could increase the internal friction angle of soil; up to 16%, and adding 5% nanoclay could increase the cohesion of soil up to 84%. It should be mentioned that the most increase in internal friction angle and cohesion in nanosilica-improved samples were observed in samples improved with 0.75% and 0.15%, respectively, which had increased the internal friction angle of soil at 22% and cohesion at 108%. Besides, comparing the results of the shear strength test of soil showed that the shear strength parameters in nanosilica-improved samples showed a sudden decrease and increase; although the changes in nanoclay samples were gradual. The changes can be because of the closeness of mechanical properties of nanoclay to the studied soil, and the highest level of water absorption was observed in nanosilica-improved samples.

The results of laboratory investigations showed that for the same ratio of additive in the soil improved by 1% nanosilica, compressive strength was increased at 620% and precipitation was decreased at 86%. However, in the soil improved by 1% nanoclay, compressive strength was increased at 134% and precipitation was decreased by 86%.

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