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Experimental Investigation on Geotechnical Behavior of Collapsible Soils Improved with Nanomaterials

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ABSTRACT: Collapsibility is the sudden change of the soil volume due to the loss of the bonding forces of soil particles. The collapsibility in sands is caused by the sliding of the saturated clay that sticks the sand particles, while the collapse phenomena of the clay are caused by the loss of the electrochemical bond that has formed on the outer surface of the clay plates. Considering that the phenomenon of subsidence has caused many problems in buildings and structures, it is very important to pay attention to the behavior of this type of soil and its improvement. In this research, the effect of nanomaterials on the collapsibility potential of soils has been investigated. The volume change behavior, the collapsibility potential, and the shear strength improved under the effect of Nano-silica, Nano-clay, Aluminum Nano-oxide and Calcium Nano-carbonate have been considered. The results showed that the soil collapsibility index with the addition of Nano-silica and Nano-clay has a significant reduction in the collapse potential, but the Calcium Nano-carbonate and Aluminum Nano-oxide, have less effect on collapsibility reduction. Furthermore, the Nano-silica and Nano-clay increase the adhesion coefficient, while Nano-calcium Carbonate and Nano-silica have the greatest effect on the internal friction angle of the soil. Also, the scanning electron microscope (SEM) photography showed that the soil has microscopic pores and becomes less with the addition of nanomaterials. The soil pores and the soil texture become denser, and as a result, it reduces the collapse potential.

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1- Introduction

In the field of geotechnical engineering, soils that pose a risk or danger to construction projects are known as problematic soils. These soils may exhibit unstable or unpredictable properties that can endanger the stability and safety of a building or structure. It is crucial for engineers and builders to identify and address problematic soils during the planning and design stages of a construction project to ensure the safety and durability of the structures. One of the types of problematic soils is collapsible soil, which experiences a sudden decrease in volume with an increase in humidity due to the sudden loosening of the intergranular bond[1, 2]. Generally, and widely, chemical stabilization is used to improve the mechanical properties of problematic soils[3, 4].

Today, in addition to traditional materials such as cement and lime, nanomaterials are also used for the chemical stabilization of problematic soils. The most widely used types of nanomaterials in the field of improving problematic soils are nano lime, nano silica, nano bentonite, nano zeolite, nano montmorillonite, and nano aluminum [5].

Despite numerous theoretical and laboratory studies, the necessity of using nanomaterials to improve the soil collapsibility potential and the comparative study of the effect of nano additives with different percentages is noticeable. Therefore, geotechnical engineers can overcome collapsible soils' challenges with new data. In this research, the effect of four nanomaterials, including nano silica, nano clay, nonaluminum oxide, and nano calcium carbonate, on clayey soil's collapsibility was investigated. The collapse potential and direct shear tests were used as the main criteria for evaluating the performance of nanomaterials on soil improvement. Finally, to gain a better understanding of the microstructural improvement, scanning electron photography (SEM) was performed on some specific samples.

2- Materials and Methods

2- 1- Soil

The studied soil was taken from a depth of 1.5-2 meters with a moisture content of 3.2% from the Allah Abad region in Kerman, located in the southeast of Iran. In order to understand the mechanical characteristics of the soil, the gradation test according to ASTM D422-63, Atterberg limits according to ASTM D4318, and Proctor compaction test according to ASTM D698 were performed. Figure (1) shows the particle size distribution of the soil. According to the results and the unified classification system, the studied soil was classified as clay with low pasty properties (CL).

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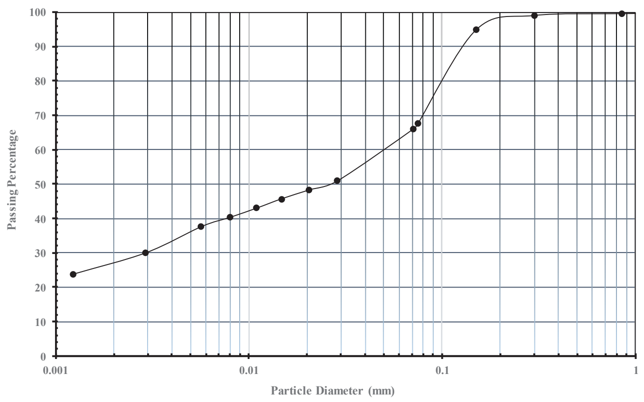

Fig. 1. The particle size distribution of the soil

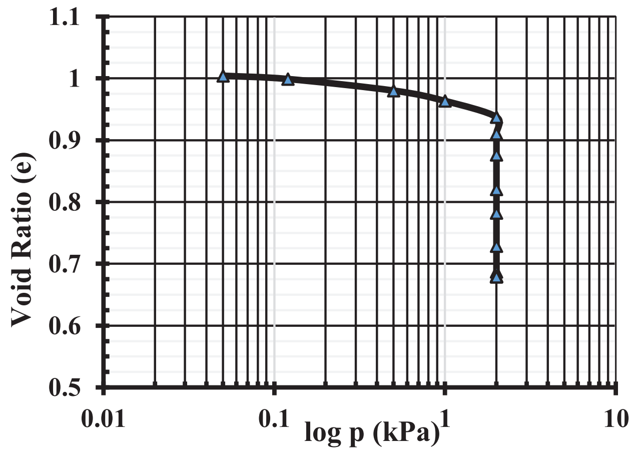

Fig. 2. The result of the collapse potential test of the soil

2- 2- Nanomaterials

In this research, four nanomaterials were used, including nano silica, nano clay, aluminum nano oxide, and calcium nano carbonate. Commonly, in soil improvement using nanomaterials, up to 2% of the soil is replaced with nanomaterials, and this percentage is relatively economical. Thus, in this research, nanomaterials with percentages of 0.5, 1, 1.5, and 2% were used. Also, the unstabilized soil sample has been considered as a control sample to evaluate the effectiveness of using nanomaterials.

2- 3- Collapse Potential Test

In this research, the soil's collapse potential test was performed according to the ASTM D5333-03 standard. This test was considered the primary criterion for evaluating the performance of nanomaterials on the improvement of collapsible soil[6].

Remolded specimens were made in a consolidation test ring with a diameter of 5 cm and a height of 2 cm. Firstly, to make the samples, by the dry mixture method, the needed amount of dry materials (soil + nanomaterials) from each composition was measured using a scale with an accuracy of 0.01 grams. Then, they were blended for 10 minutes to reach a homogeneous mixture[7]. After that, the required amount of water equal to the natural soil moisture was added to the dry mixture and mixed for 15 minutes to prepare a uniform mixture. The samples were placed in plastic bags for 24 hours. Finally, the appropriate amount of the final mixture was poured into the mold in three layers, and each layer was compacted to reach the considered constant volume. Two samples were made of each compound, and the reported numbers are the average of the two samples. Figure 2 shows the result of the collapse potential test on Allahabad's soil.

2- 4- Direct Shear Test

The direct shear test was conducted according to the ASTM D3080 standard to determine the soil's shear strength, the angle of internal friction, and the cohesion. The samples for this test were made in the form of a square with dimensions

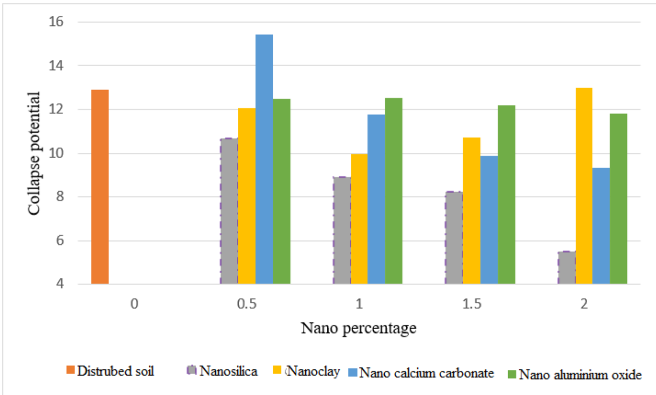

Fig. 3. The effect of the usage of used nanomaterials on the collapse potential of the soil

of 6 x 6 cm and a height of 3 cm according to the method mentioned in the previous subsection.

3- Results and Discussion

Figure (3) shows the effect of nano aluminum oxide, nano calcium carbonate, nano clay, and nano silica on Allahabad's soil's collapse potential. It can be clearly seen that using all four nano additives resulted in reducing the collapse potential index. The results show that adding nano-silica to Allahabad's soil has a more significant effect than adding other additives for soil improvement. According to the microstructural investigations, Allahabad's soil had microscopic voids and pores. The addition of nanomaterials filled the existing voids and created a correlation between soil particles.

4- Conclusions

By the addition of nanomaterials (nano aluminum oxide, nano calcium carbonate, nanoclay and nanosilica) to the soil, the collapse potential decreased considerably.

The addition of nanosilica to the CL clayey soil has a more significant effect than adding other additives.

As the percentage of nano-silica and nano-calcium carbonate in the soil increases, the effect of reduction in the soil's collapse potential becomes more intense.

By comparing the microstructural images of stabilized specimens using nano calcium carbonate and nano aluminum oxide, it can be seen that in the same percentage of both substances, calcium carbonate has bonded with more soil particles.

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