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Evaluating the Effects of Lime and Nano-Lime on Compaction and Strength Properties of Chalus Coastal Sand

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1. Introduction

Iran contains problematic soilincluding soft soil, expansive soil, collapsible soil, and soils with low bearing capacity or high sensitivity to moisture changes. Lime or cement can be addedinto the problematic soil to form lime or cement-stabilized soil which isone of the methods of soil improvement.

In addition to traditional methods of soil stabilization, interest in the use of chemical additives at the nanoscale has increased considerably in recent years among geotechnical researchers.

Nanomaterials describe materialswhose size is less than 100 nanometer.Nanoscale particles exhibit very different behaviors, compared to larger particles.

Various studies have been conducted to evaluate the effect of different additives onthe mechanical and engineering behavior of soil deposits.

The results of previous studies have shown that the addition of lime caused an increase in shear strength of gravel sand. The addition of 4.5% lime increased the cohesion of the soil by about 10 times and the friction angle by about 1.1 times. The strength of soil increased by 3.5 times after 1000 days by adding 33% of nano-SiO_2. The effects of nano-SiO_2 on mechanical behavior of soil-cement mixtures revealed a 100% increase incompressive strengthby adding 30% nanomaterials.

Some studies have focused on clay soils and have shown that the Atterberg limits increase by increasing nanoparticles.

It can be concluded from previous studies that adding chemical additives at the nanoscalehas a more significant effect on mechanical behavior of soil materials.

The effect of calcium carbonate (i.e., lime) and nano-calcium carbonate (i.e., nano-lime) on the mechanical properties of the Chalus coastal sand is evaluated in this study. The mixtures were prepared with different percentages of lime and nano-lime.Compaction and strength tests were performed on the mixtures.

2. Materials

The soil of the Caspian Sea is used in this study. For this purpose, the soil was obtained from the coasts of Chalus cityin the north of Iran.To evaluate the physical properties of the soil, various index tests were carried out. The results showed that Chalus sand can be classified in poorly-graded soil.

Table 1 shows the physical properties of nano-calcium carbonate (i.e., nano-lime) used in this study.

Table 1. Physical properties of nano-lime

Property	Value
Average particle size (nm)	60
Specific surface (cm^2/gr)	60-80
Melting point (^{0}C)	825
Purity (%)	99
pH	8-10.5

3. Sample preparation

To evaluate the effect of lime and nano-lime on compaction and shear strength behavior, Chalus sand was mixed with different percentages of additives, including 1, 2, 3, 6 and 9%. The mixtures were tested by standard proctor and direct shear tests. It should be noted that the dry deposition method was used for sample preparation in this study.To better compare the results of the direct shear tests, the initial conditions for all natural and stabilized soil samples were constant.

4. Results

To evaluate the compaction behavior of soil stabilized by lime and nano-lime, standard proctor tests were carried out on specimens with and without additives. The results showed that, firstly, increase in the water content led to an increase in the dry unit weight of the mixtures. After that, the dry density of the soil-additive mixture decreased by increasing the moisture content. This trend has been observed in soil stabilized by both lime and nano-lime.

As the lime and nano-lime particles were smaller than Chalus sand particles, the inter-particle voids in the sandy soil were filled with additive particles. As a result, the dry unit weight has been increased by increasing the amount of additives.

The specific surface of soil-lime and soil-nano-lime mixtures is increased by increasing the percentage of additives in the mixtures. A higher water content is required for the particle movement in the compaction process. The results showed thata higher water content (ω) was necessary in samples with a higher lime or nano-lime content.

The evaluation of the shear parameters of the soil mixtures, including the internal friction angle and cohesion,was carried out by direct shear tests. Based on the results of this study, the improvement of the sandy soil by lime and nano-lime resulted in an increase in shear strength.

The presence of fine particles of lime and nano-lime between the pores of the sand makes the mixture more

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solid and better transmit the stresses between the grains. The cementation caused by chemical reactions also increased the hardness and resistance of the mixture.Due to the greater impact of lime particles at the nanoscale on the intensity of chemical reactions, the increase in shear strength of the soil-nano-lime mixture was greater than that of the soil-lime mixture.

5. Discussion

An increase in the percentage of additives (i.e., lime and nano-lime) leads to a linear increase in the maximum dry unitweight and the percentage of optimum moisture. However, the impact of calcium carbonate with nanoparticles is greater than the one with natural size, and the slope of the line related to the soil stabilized by the nano-lime is greater.

By adding 3% of nano-lime to the sandy soil, the maximum dry unitweight increases by about 4% compared to the state without additives. However, the increase in this parameter in the mixture of soil stabilized with 3% lime is approximately 1.3%.This suggests that adding calcium carbonate at the nanoscale speeds up and intensifies the hydration processes, thereby increases the efficiency of soil compaction operations.

The addition of lime and nano-lime significantly affects the optimum water content of the mixture. The percentage increase in optimummoisture content when using 3% lime and nano-lime is 4.8% and 26.9% respectively.The slope of the percentage change in the optimum water content in the sand-nano-lime mixture is about 1.9 times the slope of the changes in the sand-lime mixture.

Chemical reactions, including cementation and pozzolanic reactions, due to the presence of calcium carbonate, cause the adhesion of certain grains and thus form larger grains with rougher and angular surfaces. As a result, the friction angle increases.By adding calcium carbonateto the soil, hydrated silicate cement gels are formed as a result of chemical processes. These cement gels penetrate between the soil pores and increase the cohesion between soil particles.On the other hand, due to the presence of very fine particles in the nano-lime, the pH of the soil increases and the pozzolanic reaction rate increases, which means that the addition of nano-lime increases the shear strength of the soil more than adding lime.

6. Conclusion

Some of the most important conclusions ofthis study are:

1. The improvement of Chaluscoastal sand by the lime and nano-lime stabilization method improves the compaction properties (increase in dry unit weight) and the shear strength parameters (increase in internal friction angle and cohesion) of the soil.
2. By adding 3% lime and nano-lime to the sandy soil, the values of dry unitweight increases by approximately 1.3% and 4%, respectively, compared to the state without additives. This indicates a greater impact of nano-lime in accelerating and intensifying hydration processes and therefore increasing the efficiency of soil compaction process.It should be noted that to obtain the maximum unitweight, more water is needed in the stabilized soils. For example, the optimummoisture content increases by 27% when adding 3% nano-lime.
3. Chemical reactions such as hydration, cementation, and pozzolanic reactions cause the agglomeration process, resulting in the formation of larger grains with rougher and more angular surfaces than the original soil. For this reason, the internal friction angle of the stabilized sand increases.
4. The main reason for the increase in soil shear strength due to stabilization with lime and nano-lime is the increase in the cohesion of soil particles. Hydrated silicate cement gels penetrate into the soil pores and increase the cohesion between soil particles.