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Evaluating the effect of using iron nanoparticles on geotechnical parameters of soils contaminated with cadmium

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ABSTRACT: In the present day, the widespread environmental issue of soil and groundwater contamination with hazardous and harmful pollutants has garnered significant attention. The change in the soil's geotechnical characteristics is one of the most significant consequences of the entry of metal contaminants into the soil. Different methods are used to reduce the amount of pollution and stabilize soils contaminated with heavy metals, one of these methods is the use of zero-valent iron nanoparticles. In this study, the effect of using zero-valent iron nanoparticles on the stabilization of cadmium-contaminated soils has been investigated. The base soil samples investigated in this study were a combination of clay and sand. After making the base soil samples, the base soil samples were contaminated with cadmium with concentrations of 10, 20, 40, and 60 ppm. After contamination of the samples with cadmium, zero-valent iron nanoparticles were added to the contaminated samples to stabilize the contaminated samples. Finally, on all the samples, tests of Atterberg limits, unconfined compressive strength, and compaction were performed. The results of the tests performed on the contaminated samples without stabilizers showed that with the increase in the pollutant concentration, the Atterberg limits of the samples decreased, the maximum dry unit weight increased, the optimum moisture content and the unconfined compressive strength of the samples decreased. On the contrary, the results of the tests conducted on the contaminated samples stabilized with zero-valent iron nanoparticles indicated that the unconfined strength of the contaminated samples stabilized with zero-valent iron nanoparticles was increased compared to the contaminated samples without any stabilizer. The results of the unconfined compression tests showed that the uniaxial stress of the samples with iron nanoparticles increased by 45.6, 63, 67.1, and 67.7%, respectively, compared to the same samples contaminated with cadmium without iron nanoparticles.

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1- Introduction

The use of soil is inevitable in most construction projects, and in many structures, it has a fundamental role and a special contribution to the economy of the project in the stages of study, design, construction, and maintenance. Removing or improving the unfavorable characteristics in the soil to build the structure is one technique to make the best use of it if the resistance and environmental elements required for the construction of the structure are absent. Numerous studies in the past have addressed various approaches to enhance and adjust polluted soils with regard to resistivity and geotechnical characteristics [1-4].

Numerous studies have been carried out to date regarding the stabilization of heavy metal-contaminated soils using various nanoparticles; however, only a limited amount of previous research has examined the impact of using iron nanoparticles on the geotechnical parameters of soils contaminated with heavy metal cadmium. Thus, iron nanoparticles were used in this study to test the stabilization of cadmium-contaminated soils. The study aims to examine the influence of cadmium concentration, considered a pollutant, and the quantity of kaolinite in the soil on the behavior of samples stabilized by zero-valent iron nanoparticles. To achieve this, soil samples with varying kaolinite percentages will be subjected to contamination with different cadmium concentrations (10, 20, 40, and 60 ppm). Subsequently, cadmium-contaminated samples will be treated with iron nanoparticles to stabilize them. Finally, the manufactured samples will undergo testing for Atterberg limits, compaction, and unconfined compressive tests to investigate the impact of nanoparticle utilization on the geotechnical properties of cadmium-contaminated soil.

2- Methodology

The experiments conducted within this study are divided into two principal stages. In the first part of the tests, samples

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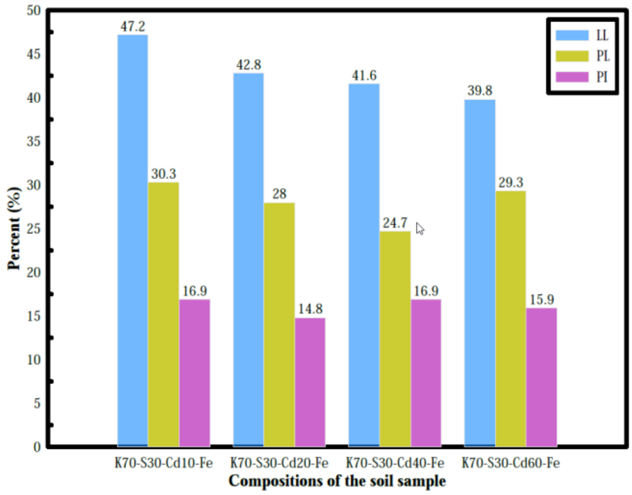

Fig. 1. Atterberg limits of iron nanoparticle-immobilized cadmium-contaminated soil samples

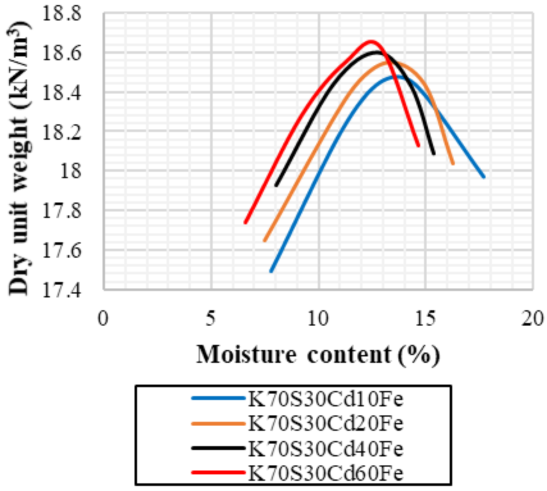

Fig. 2. Compaction curve of iron nanoparticle-immobilized soil samples contaminated with cadmium

of base soil and contaminated soil were prepared and examined under various tests. The base soil samples included 3 main samples, which consisted of 60, 65, and 70% kaolinite clay and 40, 35, and 30% sand, respectively. To create soil samples contaminated with cadmium, an initial solution was prepared by dissolving 0.14 grams of cadmium nitrate tetrahydrate in 1 liter of distilled water. Subsequently, quantities of 1, 2, 4, and 6 cc of this solution, equivalent to 10, 20, 40, and 60 ppm of cadmium contamination, were separately introduced to all three soil compositions (K60, K65, and K70), each consisting of 5 grams of soil. The mixtures were then subjected to 48 hours of continuous stirring using a magnetic stirrer at a consistent speed. The stirring aimed to ensure uniform distribution of both moisture and contaminants within the soil.

The second phase of the experiment involved adding nanoparticles to the contaminated soils and maintaining the suspension for 24 hours on a magnetic stirrer in a lab setting. The suspension contained 4 percent by weight of the soil and was made of a combination of zero-valent iron and CMC[1]. HNO3-acid and NaOH bases were also used to estimate the desired pH (7.07). Subsequently, the samples were put in the oven to finish drying. Finally, all the samples were subjected to Atterberg limits, compaction, and unconfined compressive tests.

3- Results and Discussion

3- 1- Atterberg limits of stabilized soil

The experimental results indicate that when iron nanoparticles are incorporated into cadmium-contaminated soil, both the liquid limit and plastic limit of the contaminated soils decrease as the pollutant concentration increases.

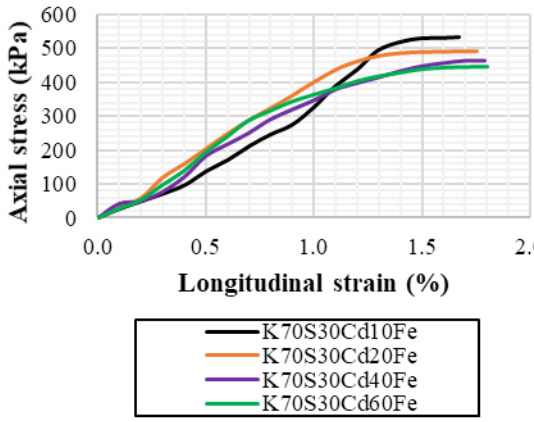

Fig. 3. The iron nanoparticle-immobilized stress-strain curve of cadmium-contaminated soil samples

3- 2- Stabilized soil's compaction test results

Introducing iron nanoparticles into the contaminated soil samples has caused a reduction in the dry unit weight of the cadmium-contaminated samples and an enhancement in the optimum moisture content, as compared to samples without iron nanoparticles.

3- 3- Unconfined Compressive Strength of the Stabilized Soil

The introduction of iron nanoparticles results in an enhancement of the soil's compressive strength, surpassing that of uncontaminated conditions, particularly at low cadmium levels. Incorporating iron nanoparticles into cadmium-contaminated samples initiates cation exchange reactions between the iron nanoparticles and the cadmium-

1 Carboxymethyl cellulose

contaminated soil samples. These reactions promote greater cohesion in the samples compared to those contaminated with cadmium but lacking iron nanoparticles. Consequently, the maximum uniaxial stress in the samples increases. Conversely, as the pollutant concentration rises, the cohesion of the samples diminishes, leading to a decrease in their uniaxial stress.

4- Conclusions

- Iron nanoparticles increase the soil's compressive strength, making it superior to the uncontaminated state even in cases of low cadmium levels.
- The addition of zero-valent iron nanoparticles causes the soil's dry unit weight to drop once more while increasing its optimum moisture content. This is most likely because the cadmium ions regenerate, increasing the double layer's thickness.
- Atterberg limits are significantly increased by the addition of zero-valent iron nanoparticles, to the point that in certain instances their values after modification exceed those of uncontaminated soil.

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