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Improving the Behaviors of a Clay Soil Contaminated with Phenanthrene using MgO

Mohadeseh Amini[1] Ali Raeesi Estabragh[2]
Jamal Abdollahi Ali Beik[3]

1. Introduction

Soil improvement, in its general meaning, considers every physical, physicochemical, and chemical method employed to make a soil suitable for its required engineering purpose. Several methods have been used to improve the behaviors of contaminated soils over the past few decades. Among these methods, the chemical technique of lime or cement-based soil mix technology has been widely applied and studied by a number of researchers. Portland cement (PC) is the most popular material for improvement the soils. However, the procedure of PC is known to be high energy-consuming and releases high value of CO_2 during its production process. Recently materials such as MgO have been drawn the attention of researchers for replacing the PC. In addition to its economic and environmental advantages, the hydration of MgO also gives an equilibrium pH of about 10.5 that has better precipitation action in comparison with lime and cement. A Review of the literature shows that to date very limited studies about the effect of MgO on the improvement of contaminated soil can be found. Hence, the main objective of this work was to study the behaviors of a contaminated soil with phenanthrene using different percentages of MgO through experimental tests. Atterberg limits and standard compaction tests were conducted on the mixtures. Moreover, unconfined compressive strength (UCS) and SEM tests were conducted on compacted samples from the natural soil and the above mixtures at different curing times. The results are compared with the results for stabilized uncontaminated samples at the same conditions as the contaminated soil samples.

2. Materials and Methods

The main materials that were used in this study were soil, phenanthrene, acetone, and MgO. The soil was clay soil and was prepared from Qazvin province. The grain size distribution test showed that the soil consisted of 2% sand 45% silt and 53% clay. The liquid limit and plastic limit of the soil were determined as 47 and 26 % and its specific gravity was 2.7. The soil was classified as clay with low plasticity (CL) according to the Unified Soil Classification System (USCS). The maximum dry unit weight and optimum water content of the soil were determined from the standard compaction test as 16.8 kN/m^3 and 18% respectively. Phenanthrene with a concentration of 1200 mg/kg was used for preparing artificially contaminated soil. The solubility of phenanthrene in water is very low (1.15 mg/l), but it is completely dissolved in acetone. Therefore, acetone with a purity of 99.9% was used as a solvent for phenanthrene in making contaminated soil. After preparing the solution of acetone-phenanthrene it was sprayed on the soil and mixing was done by hand. The mixture was kept in the open air to allow evaporation of the acetone from the soil mass. Then the soil mass was kept in a plastic bag for the completion of the interaction between soil and phenanthrene. Natural air-dried soil and contaminated soil were mixed with 5, 10, 20, and 30% (by weight) of MgO. A number of experimental tests including Atterberg limits, compaction, UCS, and SEM tests were performed on samples of natural soil, mixtures of natural soil with MgO, contaminated soil, and mixtures of contaminated soil with different percents of MgO according to the ASTM standard. The samples for strength tests were made by static compaction method at optimum water content and maximum dry unit weight that were obtained from corresponding compaction curve for each of used materials. The length and diameter of samples were 100 and 50 mm respectively.

3. Results and Discussion

The results of the Atterberg limits tests show that adding phenanthrene causes a reduction in the values of Atterberg limits in comparison with natural soil. It is found the results that adding different percentages of MgO to natural and contaminated soil causes an increase of Atterberg limits, which is a function of the percent of MgO used. The reason is that the specific surface of MgO is about 250-300 m^2/g, which is more than natural soil. Hence, it has a higher potential for adsorbing water. This property of MgO causes an increase in the values of Atterberg limits of soil when it is mixed with MgO. Therefore, by increasing the percent of MgO results in increase in the Atterberg limits.

[1] Corresponding author. PhD Candidate in Hydraulic Structures, Irrigation and Reclamation Department, Tehran University, Iran. Email: amini.mohadeseh@ut.ac.ir
[2] Professor of Geotechnical Engineering, Irrigation and Reclamation Department, Tehran University, Iran.
[3] Lecturer of Civil Engineering, Irrigation and Reclamation Department, Tehran University, Iran.

The results of compaction tests show that the γ_{dmax} and w_{opt} of natural soil are 16.8 kN/m^3 and 18%. By adding phenanthrene to the soil, w_{opt} changes to 16% but the γ_{dmax} does not changed. The SEM image of contaminated soil shows that by adding phenanthrene to natural soil, the structure of it is changed to dispersed condition. It showe that the structure of soil has influences on the compaction parameters.

The results show that by adding MgO to natural and contaminated soil, γ_{dmax} decreases and w_{opt} increases. Comparing the SEM images shows that adding MgO to the soil causes an increase in the degree of flocculation of the soil structure. Therefore, based on the obtained results it can be concluded that the changes in the values of compaction parameters are due to the high water adsorption capacity of MgO because of its high specific surface and forming the new structure of the soil as shown in SEM images.

The results of strength tests indicate that the final strength of natural soil is 306 kPa at the strain of 6%. These values are changed to 203 kPa and 8.5%, respectively, for contaminated soil. It is concluded that adding the solution of phenanthrene to soil causes a reduction in the final strength in comparison with the natural soil. The results also indicate that by adding MgO to natural and contaminated soil, the final strength of them increases and the amount of it depends on the percent of MgO and curing time. At a constant percent of MgO, the strength of the soil increases with increasing the curing time. Also, at a constant curing time, an increase in the percent of MgO causes an increase in strength. This is due to the chemical reaction of MgO during the hydration process. It can be said when MgO is added to the soil, its hydration starts by adsorbing the free water between particles. During the hydration, MgO changes to $Mg(OH)_2$, which is termed brucite. Brucite reacts with CO_2 and water and produces materials such as nesquehonite, hydromagnesite, and dypingite (the carbonation products can be seen in SEM images). The carbonation process and production of the materials continue with time by adsorbing the water and CO_2 and they cause increasing the strength of the soil sample.

The modulus of elasticity corresponding to the 50% (E_{50}) of final strength was calculated with the aid of stress-strain curves for each of the used materials. The results showed that the variations of it are the function of percent of MgO and curing times similar to the variations of final strength of samples. It can be said that the carbonation products that are made during the time are important in the variation amount of E_{50}.

4. Conclusion

The following conclusions can be drawn from the obtained results of this work:

- By adding phenanthrene to soil, the structure of it changes from flocculated to dispersed condition. The Atterberg limits reduces and from compaction parameters, only the optimum water content reduces in comparison with natural soil. In addition, the final strength of it is less than the natural soil.
- MgO causes an increase in the values of Atterberg limits and compaction parameters in comparison with natural soil.
- MgO can increase the strength and E_{50} of natural and contaminated soil and the amount of increase in strength depends on the percent of used MgO and curing time.