# Investigation on the effect of cement on the treatment of a clay soil contaminated with phenanthrene

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## Extended Abstract

### Introduction

A contaminant can be described as a chemical element, ion, or compound that can be entered into the environment and has long-term or short-term effects on human life and the environment. The contaminants can be divided into two major groups namely organic and inorganic contaminants. The main sources of petroleum organic contaminants originate from many sources such as oil well drilling and production operations, transportation and storage in the upstream industry, and refinery, transportation and marketing in the downstream industry. Polycyclic aromatic hydrocarbons (PAHs) are from the class of organic contaminants. They are toxic substances and are composed of hydrocarbon molecules with two or more fused benzenes. They are made about 20-40% of the oil. There are many reports about the contaminated soil around the refineries especially with phenanthrene and the dangers of them for the environment. Spilled petroleum hydrocarbons in the environment are usually flowed into the soil due to gravity until an impervious horizontal layer is met. There are several techniques for the treatment of contaminated soils, including mechanical and chemical methods. The chemical method involves the addition of additives such as lime, cement or fly ash to the soil and new cementitious material is made and caused to enhance the physical and mechanical behaviors of the soil. Researchers such as Estabragh et al. (2016, 2018), Hajimohammadi and Hamidi (2020) studied the effects of cement on the treatment of a soil contaminated with organic contaminants. Their results showed that the cement can improve the mechanical geotechnical properties of used contaminated soil. In this study, the effect of different percentages of cement on the treatment of a contaminated clay soil with phenanthrene is studied through a set of testing program. A set of tests including Atterberg limits, compaction and unconfined compression strength (UCS) were conducted on natural and contaminated soil that were mixed with 5, 10 and 20% of cement.

The UCS tests were also performed on samples at curing times of 3, 7, 14 and 28 days. The obtained results for the treated contaminated are compared with the results of the treated uncontaminated soil and they were analyzed and discussed with each other.

**Material and methods**

The natural soil which was selected in this study was clay soil with low plasticity. Based on the Atterberg limits and grain size distribution results it is classified as CL according to the Unified Soil Classification System (USCS). Acetone was used as a solvent of phenanthrene because of its low solubility in water. Phenanthrene with a concentration of 1200 mg/kg was used for preparing contaminated soil. For the treatment of uncontaminated and contaminated soil-cement with percentages of 5, 10 and 20% were mixed with them. Experimental tests include Atterberg limits, compaction, and unconfined compressive strength, which are performed on the samples of uncontaminated and contaminated soil under the same condition. The samples for strength tests were made by static compaction method at optimum water content and maximum dry unit weight that were obtained from the compaction curve of used materials. The length and diameter of the samples were 100 and 50 mm respectively. The including tests in this work were carried out according to ASTM standards. In addition, SEM tests were also performed on different samples to get more information about the microstructure of the soil at different conditions.

**Results and discussion**

The results of Atterberg limits showed that the values of LL (Liquid Limit) and PL (Plastic limit) for natural soil are 47 and 26% respectively but by adding 5% cement to the soil they are changed to 50 and 25%. By adding cement more than 5%, the Atterberg limits are decreased in comparison with natural soil. The results show that the values of LL and PL for contaminated soil are 42 and 22% respectively and by adding 5 and 10% cement the Atterberg limits increased. For the mixture of contaminated soil with 20% cement, LL and PL are decreased and increased respectively in comparison with contaminated soil. When cement is added to the soil the structure of it is changed to a flocculated form with large spaces between particles that can hold more water. This condition is resulted in increasing the Atterberg limits. By increasing the percentage of cement more than 5% (i.e. 10 and 20%), the degree of flocculation is increased and the space between particles is reduced and resulted in decreasing the Atterberg limits. The results showed that this trend is also observed for a mixture of contaminated soil with cement.

The results of compaction tests show that the maximum dry unit weight and optimum water content of natural soil are 16.8 KN/m$^3$ and 18%. By mixing this soil with 5% cement, they are changed to 16.2 KN/m$^3$ and 19% respectively. By adding 10 and 20% cement there is an increase in maximum dry unit weight but there is not any significant change in the value of optimum water content. It can be said that by adding cement to soil an open structure is formed and particles are pasted to each other by strong bonds. In the compaction test, the amount of used energy is the same at each layer. This amount of used energy is not able to destroy the bonds between the particles in a mixture of soil and 5% cement and resulted in reduction and increasing the maximum dry unit weight and optimum water content. It can be explained that by increasing the percentage of cement to 10 and 20%, spaces between particles are filled with cement that is resulted in increasing maximum dry unit weight and a decrease in optimum water content. The results show that the maximum dry unit weight and optimum water content for contaminated soil are 16.8 $KN/m^3$ and 16% respectively. By adding 5 and 10% cement there is a decrease and increase in maximum dry unit weight and optimum water content. For 20% they are changed to 17 $kN/m^3$ and 18.5% respectively. The reason for variations in the compaction parameters is similar to the reason for the mixture of uncontaminated soil-cement.

The above results can be also explained by the aid of SEM results. SEM images show that natural soil has a flocculated fabric and adding phenanthrene to soil causes a structural change of soil that leads to the dispersed structure. By adding 5 % cement to natural soil, all cement interacts with soil particles and causes the structure of the soil is changed to flocculated condition, but by adding 20 % cement just a part of cement interacts with soil and forms a needle-shaped material (Ettringite) and the extra cement fills the spaces between the clay particles. By adding cement to the contaminated soil, because of the presence of phenanthrene in the soil and changing the soil structure, nearly all void spaces between the particles are filled by the hydration products of cement.

The results of strength tests indicate that the final strength of natural soil is 272 kPa at the strain of 6.5% and that for the contaminated soil they were changed to 188 kPa at strains of about 7.5%. By adding cement to soil and contaminated soil, the final compressive strength of the soil increases and the amount of increasing in strength is dependent on the percentage of cement and curing time. This result is due to the chemical reaction of cement hydration. The interaction between soil and cement can be divided into three stages namely cation exchange, hydration and pozzolanic reactions. When cement is added to the soil, cation exchange starts and calcium ions are released during the initial hydration of cement and cation exchange ions with soil particles is occurred. In the hydration stage, the pH of the pore water increased and the soil silica and alumina were dissolved. In the pozzolanic reaction, $Ca(OH)_2$ reacts with the released silicate and aluminate from the previous stage, and the hydrated gel of calcium silicate (CSH) and the hydrated gel of calcium aluminate (CAH) are formed.

These gels bind soil particles to each other so the particles cannot be slide over each other easily and this increases the strength of soil-cement. The higher the amount of cement and curing time, the higher the production of these materials and the result of higher strength will be observed. The results also show that the final strength of contaminated soil-cement samples is higher than the uncontaminated soil-cement samples. The reason for it can be the oxidation of phenanthrene in the vicinity of enough cement. Phenanthrene can be oxidized and produce some strong hydrogen bonds between particles, thereby increasing the strength of contaminated soil samples with cement is occurred.

**Conclusion**

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

- The strength of the natural soil is reduced by adding phenanthrene to it.
- Cement as an agent can increase the strength of uncontaminated and contaminated soil and the amount of increasing in the strength of them is dependent on the percentage of cement and curing time.
- At a given curing time, the final strength of contaminated soil-cement is more than the uncontaminated soil-cement.

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