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EXTENDED ABSTRACT

The effective parameters on deviator stress and stiffness of treated sands by microbial induced calcite precipitation

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1. Introduction

Given the population growth, one of the challenges facing engineers in the construction field is access to land with suitable bearing capacity. Therefore, the lack of access toquality land compels geotechnical engineers to enhance the mechanical parameters of soil using various improvement methods. To address these issues, research into new improvement methods such as microbial induced calcite precipitation (MICP) has expanded.

Research on the parameters influencing the efficiency of the method and the development of various biological improvement techniques has continued. For instance, Harkes et al. (2010) investigated two-phase injection to prevent the accumulation and deposition of precipitate at the injection point. Al Qabany et al. (2012) evaluated the effect of cementation solution concentration and retention time on the efficiency of biological improvement methods under constant optical density conditions. Additionally, DeJong and Montoya (2015) examined the effect of cementation degree on the stress-strain behavior of sand in CU triaxial tests.

In this study, the impact of the molarity of the cementation solution, bacterial optical density, and curing time on the stress-strain behavior and deformation parameters of sand improved through microbial induced calcite precipitation will be investigated. For each parameter influencing the improvement process, 17 samples were obtained based on experimental design using Design Expert ver. 11.0.3.0 software. After preparation, the samples were subjected to consolidated undrained (CU) triaxial compression tests. The results from the triaxial tests were then analyzed through stress-strain curves and stiffness.

2. Methodology

2.1. Sample Preparation and Testing

The soil used in this research was sourced from the Kouhin region in Qazvin province. According to particle size analysis, the soil is classified as poorly graded sand (SP). The molds were made from PVC pipes with diameters and heights of 7 cm and 14 cm, respectively, in accordance with the specifications of the triaxial testing apparatus. To prevent blockage at the injection point and ensure uniformity in the improvement process, a four-phase injection method was utilized.

Next, to improve the samples, a cementation solution was prepared based on the desired molarities (Figure 1(a)). Then, considering the curing times examined in this study, the injected samples were kept in appropriate laboratory conditions at temperatures between 27 to 30 degrees Celsius to allow for biological deposition within the pores. Figure 1(b) shows a cemented sample on the triaxial apparatus.

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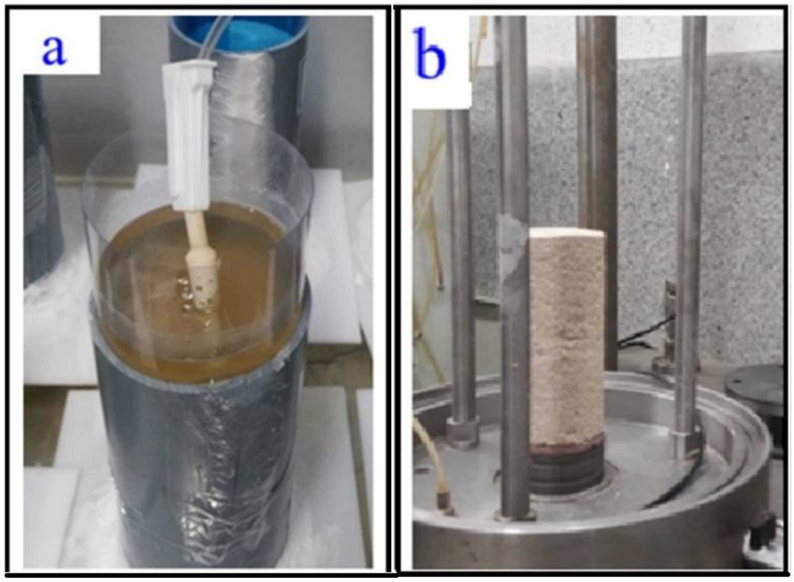

Fig. 1. (a) Cementation solution injection, (b) Treated sample in triaxial testing machine

To compare the stress-strain behavior and stiffness of samples before and after improvement, the samples were subjected to CU triaxial tests according to ASTM D4767-CU standards after being removed from the molds.

3. Discussion and Results

3.1. Comparison of Stress-Strain Behavior

Based on the results from CU triaxial tests, the maximum deviatoric stress after biological improvement was found to be 957 kPa. Additionally, the samples reached maximum deviatoric stress at axial strains of approximately 18 to 22 percent, after which they could not withstand additional loads with increasing strains. The results indicated that at lower molarity levels, the effect of molarity compared to pre-improvement conditions was not particularly significant. However, with increasing molarity and nutrient supply, better deposition occurred within the soil pores, leading to a faster increase in resistance and deviatoric stresses.

3.2. Comparison of Sample Stiffness

One of the key geotechnical parameters governing stress-strain behavior is soil modulus or stiffness. At the beginning of the CU triaxial test, samples exhibited strain-hardening behavior, and with increasing axial strain in small and elastic strain ranges, secondary modulus (E_{sec}) decreased rapidly. Subsequently, transitioning to a non-elastic region showed strain-softening behavior, where secondary stiffness (E_{sec}) gradually decreased until it approached a relatively stable value. Observations indicated that increasing the molarity of the cementation solution under similar optical density and curing time conditions resulted in an increase in secondary modulus (E_{sec}) of biologically improved samples.

The modulus (E_{50}) showed significant increases with higher molarity of the cementation solution, while after improvement through microbial induced calcite precipitation (MICP) at low molarity and optical density, stiffness did not increase significantly. The main factor contributing to the increase in secondary modulus (E_{sec}) and modulus (E_{50}) compared to pre-biological improvement conditions was raising the molarity of the cementation solution to 1.5 molar.

4. Conclusions

The molarity of the cementation solution has a significant impact on increasing the deviatoric stresses of sand improved via microbial induced calcite precipitation (MICP). Under conditions of equal optical density and curing time, an increase in the molarity of the cementation solution even resulted in an approximate 45% increase in the deviatoric stresses of the samples.

At the beginning of the CU triaxial test, the samples exhibited strain-hardening behavior, and with an increase in axial strain within the range of small and elastic strains, the secondary modulus (E_{sec}) decreased rapidly. Subsequently, transitioning to the non-elastic region showed strain-softening behavior, where the secondary stiffness (E_{sec}) decreased at a slower rate until it reached a relatively stable value. The increase in molarity, by creating more calcium carbonate precipitation between the soil pores, led to stronger contact bonds. Therefore, at lower strains, having higher strain-hardening resulted in an increase in secondary modulus (E_{sec}). A similar trend was observed concerning the equivalent stiffness at 50% of the maximum deviatoric stress (E_{50}).

5. References

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