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Effect of Microbial Stabilization on High, Intermediate and Low Compressible Clay

Hridya K SEKHARAN [a], Muhammed ADIL [a], K M MUSAMMIL [a] and Kalyani VIJAYAKUMAR [a,1]
[a] *Vidya Academy of Science and Technology, Kerala Technological University, Kerala, 680501, India*

Abstract. Engineers may have to construct structures on sites having expansive soil. By treating the soil with admixtures such as cement, bitumen, plastic, etc. Soil stabilization improves strength characteristics such as bearing capacity and unconfined compressive strength. The conventional approaches are time-intensive and are not economically viable. Through the utilization of the Microbial-Induced Calcite Precipitate technique (MICP), microbes have recently emerged to be known as a component that significantly improves the characteristics of soil. It is economical and environmentally friendly. They work on the soil to increase compaction by reducing water absorption and minimizing the void spaces between soil particles. The stabilization of soil takes place by the process of bio-cementation and bio-clogging. Calcite precipitated at the void spaces when the cementation reagent and bacterial solution were introduced to the clayey soil in various proportions. Improvements in density and strength of clayey soil are studied using Bacillus subtilis bacterium concentrations of 1 x 10^7 cells/ml, cementation reagent composed of urea and calcium chloride (0.5M, 1M, 1.5M, and 2M), and treatment intervals of (7,14, and 28 days). An unconfined compressive strength test was used to evaluate the optimum bacterial solution concentration, cementing solution molarity, and treatment duration. Maximum strength improvement ratios among the three different expansive soils were also studied. SEM analysis is carried out for the optimum combinations in the three types of soil to confirm the presence of calcite. Hence, an attempt is made to research how bacteria affect the strength of high, intermediate, and low-compressible clay.

Keywords: MICP, bio-grouting, bio-cementation, bio-clogging, bacillus subtilis

1. Introduction

In recent years, it has become difficult to carry out construction on weak soil. Soil stabilization can be defined as an alteration of the properties of the soil by physical or chemical techniques to bring changes in the engineering attributes of the soil [1]. The primary goals of soil stabilization are to enhance the soil's bearing capacity, resistance to weathering, permeability, liquefaction potential, etc. The stability of the underlying soils is critical to the long-term success of any building project. As a result, soil stabilization techniques are required to ensure the good stability of soil so that it can successfully sustain the load of the superstructure, particularly in the case of highly active soil. Chemical stabilization is often recommended for expansive soils.

[1] Kalyani VIJAYAKUMAR, Corresponding author, Vidya Academy of Science and Technology, Kerala Technological University, Kerala, 680501, India; E-mail: Kalyani.v@vidyaacademy.ac.in.

Environmentally safe practices like pre-wetting and moisture barriers are only practical for tiny, constrained places and are not suitable for huge building projects such as motorways and railways that stretch for kilometers [1-4]. Conventional ground improvement methods have several limitations. Hence, there is a need for sophisticated, long-lasting, and ecologically feasible ground improvement technology [3-6].

Microbial-induced calcite Precipitation (MICP) is just one way to stabilize soil. The MICP approach is an enhanced and more ecologically sustainable alternative to traditional technologies. Microbes are the main stabilizing component in the aforementioned strategy [5-7]. Through their metabolic activity, microorganisms have induced calcium carbonate precipitation into the soil structure to improve the engineering features of the soil. As a result, this process is referred to as MICP or microbially induced carbonate precipitation. A wide range of civil engineering fields will benefit from the successful application of MICP, encompassing retaining wall, embankment, and dam firmness, controlling soil erosion, maintaining cohesionless soils for facilitating the stability of underground constructions, improving the bearing capacity of shallow and piled foundations, and reducing the liquefaction potential of soil, etc. [6-12].

2. Experimental Study

2.1. Methodology

MICP develops its route to natural soil improvement through multidisciplinary research at the convergence of microbiology, geochemistry, and geotechnical engineering. The MICP procedure is carried out by introducing bacterial solution into soil samples, which is then followed by the protracted inoculation of cementation reagents containing urea and calcium chloride dihydrate salt (CaCl2). As a result, the soil develops calcite precipitate (CaCO3), which helps to stabilize the soil [13].

$$CO(NH_2)_2 + 2H_2O \rightarrow 2NH_4{}^{+} + CO_3{}^{2-}$$

$$Ca^{2+} + CO_3{}^{2-} \rightarrow CaCO_3$$

The soil samples were dried in the sunlight and it was autoclaved for removing contaminants. Cementation solution was made using concentrations of 0.5M, 1M, 1.5M, and 2M, and the bacterial solution containing 2%, 4%, and 6%, of the optimum moisture content of the soil were added. The bacteria decompose the urea to form carbonate ions which then combine with the calcium ions present in the cementing solution to produce calcium carbonate (Calcite) between the void spaces of the soil. Thorough mixing of the soil with the correct amount of cementation reagent and bacterial solution was done mechanically. Then samples were placed in the desiccator for a curing period of 7,14, and 28 days [1-4].

2.2. Materials Used

2.2.1. Clayey Soil

Three different types of clayey soil are taken for the experiment. High-compressible clay was taken from one of the fields in Alappuzha district. Intermediate compressible clay is taken from a field at Ottapalam Palakkad and low compressible clay is from the field located at Kechery Thrissur. The index characteristics of the soil are formulated in Table 1.

Table1. Physical and engineering properties of soil.

Description	Symbol	Soil Sample 1	Soil Sample 2	Soil Sample 3
Specific gravity	G_S	2.63	2.58	2.61
Liquid limit (%)	W_L	62	44	32
Plastic limit (%)	W_P	45	26	21
Plasticity index (%)	I_P	31	13	9
pH of sample	pH	7.53	7.82	7.91
Optimum moisture content (%)	OMC	16	14	12
Maximum dry unit weight (g/cm^3)	$\gamma dmax$	1.5	1.72	1.78
Unconfined compressive strength (kg/cm^2)	q_u	0.23	0.62	1.25
Cohesion (kg/cm^2)	C_u	0.306	1.684	2.2
Soil classification	IS	CH	CI	CL

2.3. Bacillus Subtilis -Bacteria

Bacillus Subtilis were utilized in this experiment to explore the viability of stabilizing clay of different compressibility. Pure cultural solution of Bacillus Subtilis was bought from the Department of Agricultural Microbiology, College of Horticulture, Vellanikkara, Thrissur.

2.4. Cementation Reagent

For ureolysis, a cementation solution of urea, $CaCl_2.H_2O$, and distilled water was utilized. The chemical compositions of cementation solutions for MICP treatment are shown in Table 2. 1 liter of distilled water was combined with urea, $NaHCO_3$, $CaCl_2.2H_2O$, and NH_4CI, and the pr3. TREATMENT PROCESS

The effect of microbial stabilization was studied by an unconfined compressive strength test thereby helping to evaluate the optimum bacterial solution concentration, cementing solution molarity, and treatment duration. Maximum strength improvement ratios among the three different expansive soils were also studied. SEM analysis is carried out to find the optimum combinations in the three types of soil to confirm the presence of calcite precipitate.

Table 2. Composition of cementation solution.

Molarity (M)	$Co(NH_2)_2$ (urea)	$CaCl_2$	Nutrient broth	Distilled water	Ammonium chloride	Sodium bicarbonate
0.50	32.00g	53.50g	3.00mg	1000mL	4.1g	2.12g
1.00	64.00g	107g	3.00mg	1000mL	4.1g	2.12g
1.50	128.00g	214g	3.00g	1000mL	4.1g	2.12g
2.00	256.00g	428g	3.00g	1000mL	4.1g	2.12g

3. Results and Discussions

3.1. Serial Dilution

Serial dilution is done to confirm the bacterial growth in the treated soil sample. From figure 1, it is inferred that the concentration of bacterial growth at curing periods of 7 and 14 days. It was observed that 1 colony of bacteria was seen on the 7th day while 2 colonies of bacteria were observed on the 14th day with a concentration of 10^6 cfu/g. Hence this test confirms the bacterial growth in the sample treated.

RESULTS

Sl. No.	Parameters	Observed values (cfu/g)	Remarks
1	S1	1×10^6	-----
2	S2	2×10^6	-----

The above result reported pertains only to the sample submitted in this lab. The undersigned does not guarantee the same results for the bulk or other samples.

Figure 1. Test result of serial dilution.

Unconfined compressive strength was performed for three soil samples taken to check the effectiveness of MICP in stabilizing the soil. It was observed that the maximum UCS value of 1.02kg/cm^2 was obtained for 6% bacterial solution and 0.5M cementing solution in CH soil while CI and CL soil had optimum of 2.37 kg/cm^2 and 4.01 kg/cm^2 respectively at 4% bacterial solution and 1M cementing solution for a curing period of 28 days. The UCS value was very high for 0.5M and 1 M of cementing medium for CH and the other two soils because the amount of urease in the solution hydrolyses almost all the urea. When the concentration increased to 1.5M and 2M, the strength declined. This might be because of the inhibitory impact on microbial activity, which can restrict urease synthesis. Furthermore, a lower Calcium chloride concentration leads to more homogenous calcite crystal formation at particle contact locations, which adds to strength increase with little soil disturbance. Figures 2, 3, and 4 represent a graphical representation of UCS values obtained for a curing period of 7,14 and 28 days.

The effect of MICP can be inferred by finding the strength improvement ratio. It can be defined as the ratio of UCS stabilized to UCS unstabilized. A graphical representation of the strength improvement ratio for three soils a shown in figures 2, 3, and 4

The strength improvement ratio was relatively higher for CH soil when compared to CI and CL soil. This is due to the reason that CH soil has very fine particles as well as a very compact arrangement in soil structure. So, a strong bond is created by particle-particle interaction with the calcite which is precipitated in between the void spaces. Hence this helps in the dense arrangement of soil particles.

CI and CL soil, even though offering optimum pore size for microbial movement, had a coarser arrangement of soil particles which led to lesser particle-to-particle interaction. Hence the calcite bond formation was relatively weaker. In other words, the

CH soil type offered a more specific surface area for bond formation of calcite precipitates than CI and CL soil. This led to a stronger bond formation in the CH soil type. MICP was found to increase the undrained cohesion of soil. Enhanced strength parameters can be co-related with other properties and possible implications will further lead to increased bearing capacity, minimized settlements, reduced permeability of soil shrink-swell behavior, and even reduction and a check in the development of pore pressure within the soil matrix.

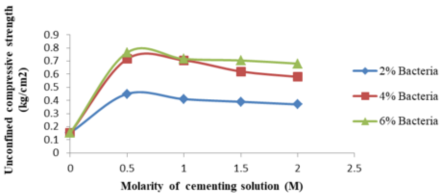

Figure 2. UCC vs. Molarity of Cementing Solution (7 days).

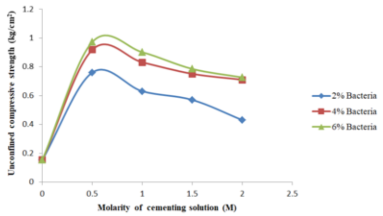

Figure 3. UCC vs. Molarity of Cementing Solution (7 days).

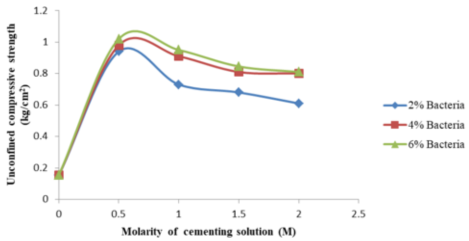

Figure 4. UCC vs Molarity of Cementing Solution (28Days).

4. Conclusions

MICP was employed successfully to change the behavior of three clayey soils with variable plasticity properties.

The unconfined compressive strength of the three expansive soils has been increased with the increase in the curing period as the improvement ratio was higher at 28 days strength when compared to 7 days strength.

It was observed that optimum strength in low and intermediate compressible clay was achieved in 1M cementing solution and 4% bacterial concentration.

Optimum strength in high compressible clay was gained in 0.5M cementing solution and 6% bacterial concentration.

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