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Effect of Microbially Induced Calcite Precipitation on Geotechnical Characteristics of Soil

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Abstract- These days new development on frail soils has turned out to be unavoidable attributable to the developing overall shortage of land. Most of available soil stabilization techniques depend on mechanical or artificial materials which are costly and require considerable energy for their application or installation and having anti-environment footprints. Microbiologically induced calcite precipitation is one such biologically driven calcite precipitation technology which has the potential for soil stabilization with feasible and environment agreeable properties. In this study urea hydrolysis process is used for calcite precipitation. The aim of this study is to examine the effect of Microbially Induced Calcite Precipitation (MICP) on permeability and strength characteristics of sandy soil having different particle size distribution. For this, soils having different particle size distribution were treated with MICP. In this study Bacillus subtiles was used to activate and catalyze the calcite precipitation caused by reaction between urea and calcium chloride. It was observed that with the use of MICP, there was a noticeable improvement in the unconfined compressive strength and reduction in permeability of soils.

Keywords: Microbial-Induced Calcite Precipitation, Soil Improvement, Shear Strength, Permeability, Bacillus subtiles.

I. INTRODUCTION

These days new development on frail soils has turned out to be unavoidable attributable to the developing overall shortage of land. Current techniques for soil stabilization includes: mechanical methods, stabilization with additives, sand columns, chemical injection and grouting. However, these technique are expensive and impractical for large scale treatment and cause serious environmental problems and contribute to disrupting the ecosystem. Soil stabilization methods requires development to guarantee viable and effective improvement while having feasible and environment agreeable properties. The multidisciplinary explore between geotechnical engineers and microbiologists had made ready for another outskirts of technology, microbial geotechnology. This acknowledgment gave the designers a chance to see the soil as a living biological system and not as a latent building material. A moderately green and reasonable soil stabilization method had been presented called microbiologically induced microbial calcite precipitation (MICP). Victoria [19] treated an five meter sand colmn with bacteria and reagents and monitored the injection process. They found that bacteria and reagents could be injected throughout the length without clogging and considerable improvement in the bearing capacity of soil. Ahmed Al Qabany [13] and Wei-Soon Ng [12]list out the various factors which affects the efficiency of Microbial Induced Carbonate Precipitation and its potential application in soil improvement. Donovan [10] summarised the state of art review of biocementation by Microbially Induced Calcite Precipitation (MICP) for Soil Stabilization.

Microbial Induced Carbonate Precipitation (MICP) is a biochemical process driven by microbes that interact with a chemical solution containing calcium and form precipitates. The chemical reaction of MICP by hydrolysis of urea given as:

$CO(NH2)2 + 2H2O = 2NH4+ + CO3-$

$Ca2+ + CO32- = CaCO3$

In the process of hydrolysis of urea, 1 mole of $CO(NH2)2$ under the action of urease producing bacteria is hydrolysed in 2 moles of ammonium cations ($NH 4+$) and 1 mole of carbonate anion ($CO32-$). During the precipitation of calcium carbonate, calcium cation ($Ca2+$), obtained from reagent solution containing calcium chloride, react with the $CO32-$ to form 1 mole of $CaCO3$.

II. MATERIALS

2.1 Microorganisms

An isolated bacterial culture of Bacillus subtiliswas used in this study. This culture is grown in controlled pH conditions for which a buffer solution was used. the buffer solution contains 13 gm of nutrient broth per liter of water Final pH of buffer solution at 250C is 7.4. Before adding bacterial culture to buffer solution the solution was sterilized by autoclaving at 15 lbs. The optical density of the culture used in this study is 1.

2.2 Cementation Reagents

The cementation reagents employed in this study comprised 0.5 M solution of urea (CO (NH2)2) and calcium chloride (CaCl2).

2.3 .Sand

Two types of sand having different particle size distribution are used in this study. The grain size distribution of this sand was determined in general accordance with IS: 2720 (Part 4) - 1985 Methods for test of soil (Part 4: Grain Size Analysis).

Table 1: Characteristics of Sand

Characteristics	D50	Cu	Cc
Sample 1	0.257 mm	0.972	1.877
Sample 2	0.486 mm	0.964	1.318

III. METHODOLOGY AND TESTS

3.1 Specimen Preparation

Different methods are used to introduce bacterial culture and reagents in sand samples for permeability and unconfined compression strength. For permeability bacterial culture and reagents was allowed to flow through specimen under pressure and for unconfined compression strength percolation method was used for bacterial culture and reagents placement.

Figure 1: Microbially Treated Sand D_{50} = 0.257 mm

Figure 2: Microbially Treated Sand D_{50} = 0.486 mm

3.2 Permeability

This test is conducted in order to find the coefficient of permeability. The coefficient of permeability of this sand was determined in general accordance with IS:2720 (Part 17) - 1986 Methods for test of soil (Part 17: Laboratory Determination of Permeability).

3.3 Unconfined Compression Strength

This test is conducted to find the ratio of failure load to cross sectional area of the sample if not subjected to any lateral soil. The Unconfined Compression Strength of the sample was determined in general accordance with IS: 2710 (Part 10) - 1986 Methods for test of soil (Part 10: Determination of unconfined compression strength).

IV. RESULTS AND DISCUSSIONS

4.1 Permeability

It was found that Microbial treatment is more effective on sand samples having mean particle size (D50) = 0.486 mm than sand having mean particle size (D50) = 0.257 mm as minimum coefficient of permeability of microbially treated sample having mean particle size (D50) = 0.486 mm is 0.7×10-5 cm/sec as compared to 1.4×10-4 for sample having mean particle size (D50) = 0.257 mm.

Table 2: Permeability of Untreated and Microbially Treated Samples

Sample No	D50	Bacterial Concentration	Reagent	Permeability	
				Before	After Treatment

			Concentration	Treatment	
1	0.257 mm	1.0	0.5 M	1.32×10-3 cm/sec	3.05×10-4 cm/sec
2	0.486 mm		0.5 M	1.51×10-3 cm/sec	7.00×10-5 cm/sec

4.2 Unconfined Compression Strength

The results for maximum unconfined compression strength for both sand samples when treated with bacterial culture having optical density =1 and reagent concentration = 0.5 M. It was found that Microbial treatment is more effective on sand samples having mean particle size (D50) = 0.486 mm than sand having mean particle size (D50) = 0.257 mm as unconfined compression strength = 1041.74 kN/m2 is more for mean particle size (D50) = 0.486 mm than 7.61 kg/cm2 sand having mean particle size (D50) = 0.257 mm.

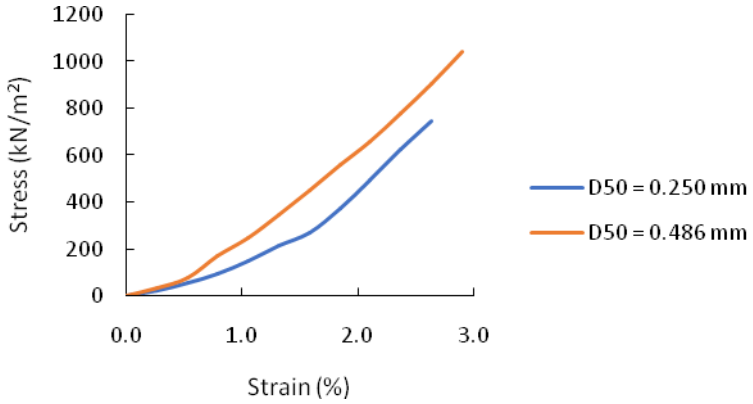

Figure 3: UCS of Microbially Treated Sand Sample (OD = 1, BC = 0.5)

4.3 Scanning Electron Microscopy for Microbially Treated Sand

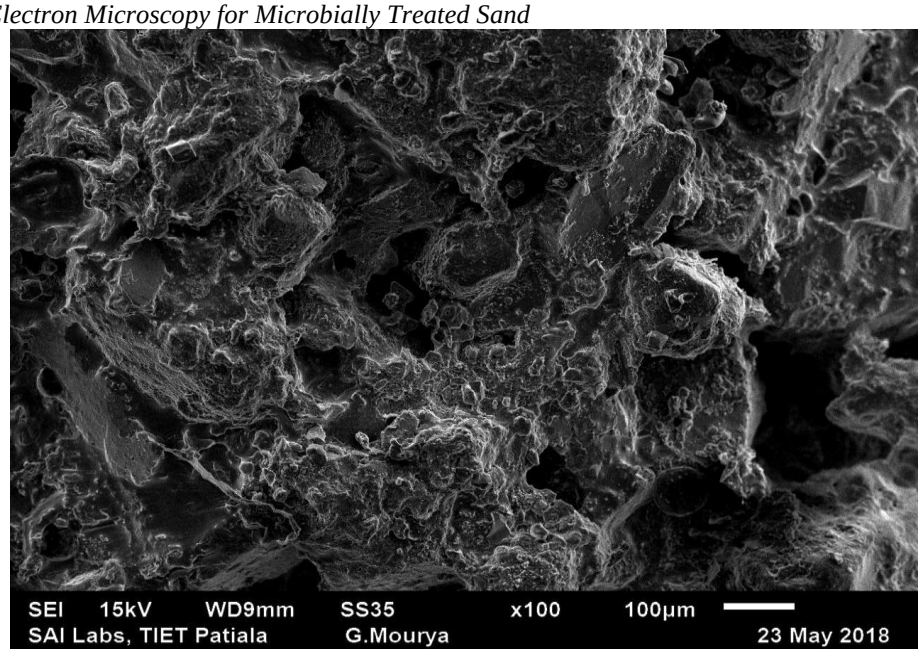

Figure 4: SEM for D50 = 0.257 mm

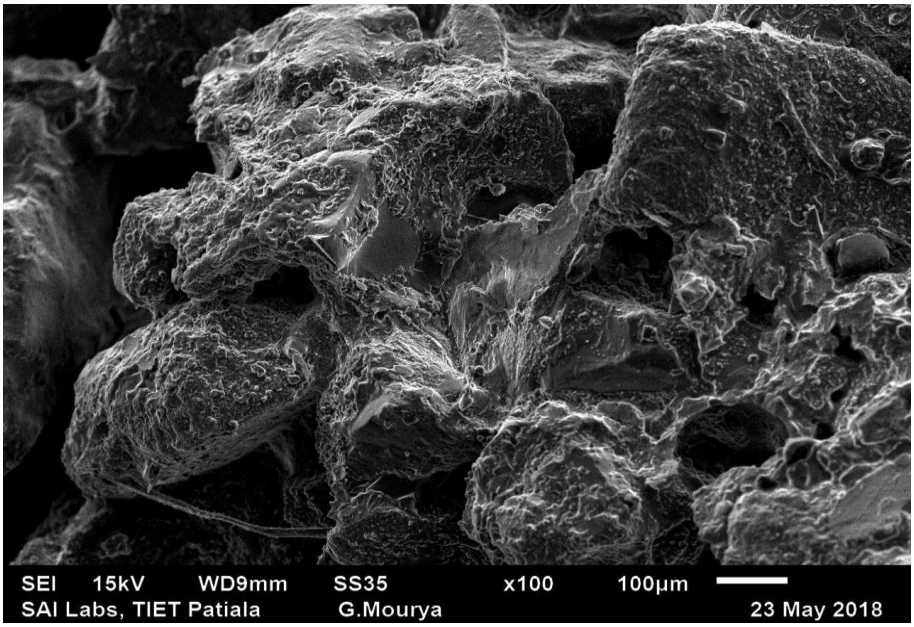

Figure 5: SEM for D50 = 0.486 mm

As shown from above SEM images it is clear that aglomoreation is more in sample having mean particle size D50=0.486 mm then the sample having mean particle size D50=0.257 mm. As more space is available in sample having higher mean particcle size so more space is availabe for bacterial action and calcite precipitation. All the discrete sand particles become one unit. Agglomeration is more significant in the sand sample having particles of higher size because there is more space available for bacterial action.

V. CONCLUSIONS

Microbiologically induced calcite precipitation treatment of soils could be used in geotechnical engineering to improve the mechanical properties of soils insitu.These methods can replace more energy demanding, expansive and environmentally unfriendly methods. Based upon this study following conclusions can be drawn:

- Coefficient of Permeability = 7.00×10-5 cm/sec for mean particle size 0.486 mm and 1.40×10-4 cm/sec for mean particle size 0.257 mm was achieved after microbial treatment.
- Unconfined Compression Strength = 1041.74 kN/m2 for mean particle size 0.486 mm and 745.78 kN/m2 for mean particle size 0.257 mm was achieved after microbial treatment.
- MICP treatment was more effective in sandy soils having higher mean particle size as there is more space available for bacterial action and calcite precipitation.

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