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ENZYME INDUCED CARBONATE PRECIPITATION (EICP) COLUMNS FOR GROUND IMPROVEMENT: REVIEW PAPER

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ABSTRACT

New alternatives in ground improvement techniques are necessary to address the significant problem of fugitive dust in arid and semi-arid regions (e.g. Thar Desert at Rajasthan in India). It can serve as a health hazard reducing technique due to fugitive dust as well as a cost effective ground improvement technique. In Enzyme Induced Carbonate Precipitation (EICP) technique the hydrolysis of urea is done from a solution of calcium chloride and urea with the help of urease enzyme. Wind Tunnel Test and Water Erosion Test indicate the control over the amount of fugitive dust as Acid Digestion and Scanning Electron Microscopy (SEM) detect the presence of calcium carbonate. Due to this technique increase in strength of soil, resistance to wind erosion, water erosion and amount of fugitive dust control can be indicated. Advantage of EICP over Microbially Induced Carbonate Precipitation (MICP) is the use of agriculturally derived urease enzyme which is more soluble in water than microbial urease and small in size. Furthermore, EICP can be used for slope stability, fugitive dust mitigation, to support embankment, to resist lateral spreading in liquefiable soils. The results can serve as an important benchmark for future application of Enzyme Induced Ground Improvement.

Keywords: *Enzyme Induced Carbonate Precipitation, Erosion, Fugitive Dust, Urease.*

I. INTRODUCTION

The 21st century has brought new challenges in all engineering fields. Huge demand of changes in ground improvement technologies is required as the established materials and methods need to be replaced by some substitutes. For example, Stabilization of soil by Portland cement is quite common and well established ground improvement technique. Now a days we can easily observe the difference in demand and supply of Portland cement as natural resources required to produce Portland cement are exhausting day by day. The production of Portland cement is extremely energy intensive and is a major source of emissions of carbon di oxide, sulphur and nitrogen oxides. Hence the necessity to replace cement by some suitable material attracted the geotechnical engineers to think about calcium carbonate precipitation by some other techniques. Initially soil was considered as dead ecosystem by geotechnical researchers but in 1970s work done by Mitchell recognized the important role that chemistry plays in fine-grained soil behavior (De Jong, et.al 2013). Then geotechnical researchers started to view the soil as a “living ecosystem". They realized the possibilities of sustainable solutions to soil improvement problems (De Jong, et.al 2011). Microbially InducedCarbonate Precipitation (MICP) recently came as an alternative to Portland cement for ground improvement (De Jong, et.al 2013). This MICP technique is sometimes termed as biogrouting (Harkey et.al 2010; Van Paassen et.al 2010). In this technique urease enzyme is produced by cultivation of bacteria and nutrients. In this process hydrolysis of urea is done with the help of microbially produced catalyst urease enzyme. Due to chemical reaction of urea and water calcium carbonate or calcite is precipitated into soil. The urease enzyme (Urea Aminohydrolase) is a widely occurring protein found in many microorganisms, higher order plants and some invertebrates. The best known urease enzyme is that extracted from the Jack-Bean (Canavalia Ensiformis) plant. Jack Bean belongs to the drought-resistant legume of the Fabaceae (or Leguminosae) family. Urease is synthesized by several families of common plants such as beans, melons, squash and plants of pine family. MICP technique relies on microbes wherein EICP technique readily available urease enzyme from agricultural sources is used in place of microbial urease enzyme. Due to plant derived urease enzyme one can easily avoid the cultivation of urease enzyme with the help of bacteria. Moreover agriculturally derived urease enzyme is smaller in size compared to microbially produced urease enzyme. Hence EICP technique can be applied to soils finer than coarse and medium sand as the big size of microbially produced urease cannot penetrate through pores of soil finer than medium sand.

The purpose of present study is to determine the effectiveness of Enzyme Induced Carbonate Precipitation (EICP) as a means of soil stabilization technique as well as fugitive dust control technique. EICP technique can solve the problem of water erosion in arid and semi-arid region (e.g. Thar Desert in India) where wind erosion is more frequent and sprinkling of water cannot be done due to less amount of water present. Fugitive dust is a health hazard to the residents of arid and semi-arid region. This study is focused on soil stabilization as well as solution of wind erosion and water erosion. Wind Tunnel experiments can show the efficiency of EICP at different wind speeds as well as different concentration of calcium chloride, urea solution with urease.

1.1 Urea Hydrolysis

Urea Agar was developed by Christensen in 1946. Urea is the product of decarboxylation of Aminoacids. Hydrolysis of urea produces ammonia and carbon di oxide. The formation of ammonia alkalizes the medium, and the pH shift is from 6.8 to 8.1.

The reaction involves two parts as follows:

$$H_2NCONH_2 + 2H_2O \xrightarrow{Urease} 2NH_4^+ + CO_3^{2-}$$

$$Ca^{2+} + CO_3^{2-} \xrightarrow{yields} CaCO_3$$

The net urease catalyzed precipitation reaction can be written as:

$$CO(NH_2)_2 + 2H_2O + CaCl_2 \xrightarrow{yields} CaCO_3 + 2NH_4Cl$$

First reaction raises the pH of the solution. This raise in pH creates the optimum condition for precipitation. When the ammonia reacts with water, it creates OH^- ions, which raise the pH of the system. This raise in pH causes precipitation. When the pH is high, we are more likely to produce carbonate (CO_3^{2-}). In this reaction urea is the source of carbonate part of calcium carbonate. Hence EICP technique involves the reaction of urea with water and calcium chloride in presence of urease enzyme.

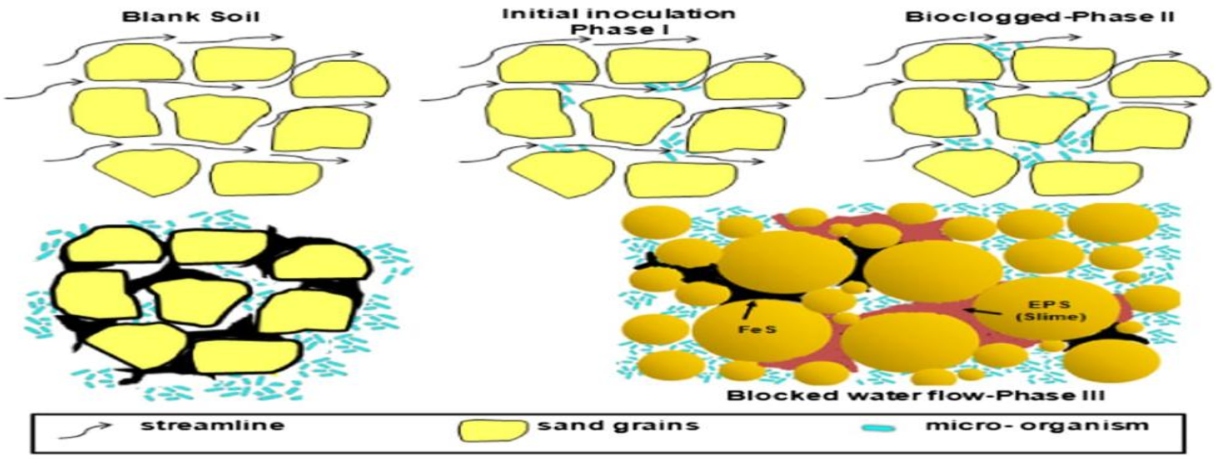

Fig 1. Bioclogging Mechanism in Soil

II. REVIEW OF LITERATURE

Enzyme Induced Carbonate Precipitation technique is similar to Microbially Induced Carbonate Precipitation except that, instead of employing microbes to generate the urease enzyme, the enzyme is obtained from agricultural sources. This study was carried out at Arizona State University, Tempe by Edward Kavazanjian and Nasser Hamdan in 2015[1]. The 20-30 silica sand had an approximate unconfined compressive strengthof 529kPa and F-60 silica sand had a peak unconfined compressivestrength of 391kPa. 1.8% of calcite content was being observed in this test. Acid digestions of approximate half-sections from mixed and compacted columns indicate that calcium carbonate ranged from 2.8% to 4.3% (w/w). The injected column that received bentonite slurry was acid digested and had a calcium carbonate content of approximately 1.8%. Cemented sand columns developed in these experiments showed substantial unconfined compressive strength indicating that EICP may potentially be used to form columns of improved soil via calcium carbonate precipitation.

The future of Microbially Induced Calcite Precepitation(MICP) technology depends upon whether native bacteria can be stimulated to facilitate the precipitation of calcite. A research program was done at the University of California- Davis by Miachael G. Gomez, Collin M. Anderson, Jason T. De Jong, Douglas C. Nelson and Xiao H[2]. Lau to access the ability of biostimulation treatment solution to stimulate native ureolytic bacteria in a variety of soils ranging from quarried sand deposits to lacustrine silty-sand deposit. A total overburden stress of 100kPa was applied to all soil columns. Treatment solutions of 300ml (urea, ammonium chloride, sodium acetate, yeast extract, calcium chloride, tris base) were applied to soil specimens twice daily. Permeability measurements were completed on both treated and untreated soil samples to determine reductions in permeability due to calcite precipitation. Unconfined Compressive Strength, Calcite content and Scanning Electron Microscopy were done. In this study highest permeability reduction is in cushion sand where $k_{final}/k_{initial}$=0.0003. Calcite ranged from 6.0% to 13.2%. Unconfined Compressive Strength ranged from 5.34MPa to 1.07MPa. In this study a reduction in permeability was shown as much as 4 orders of magnitude. Hence in this study, biostimulation techniques were shown to successfully stimulate native ureolytic bacterial populations.

The success of any technology depends upon its large scale application in any field. Hence in 2010 Leon A. Van Paassen, RanajitGhose, Thomas J.M.Vander Linden, Wouter R.L. Vander Star and Mark C.M.VanLoosdrecht [3]carried out a large scale biogrout experiment (100m^3) was conducted. The sand originated from a quarry in Itterbeck, Germany. The sand was poorly graded, fine to medium grained. The geophone arrays remained untouched for the entire duration of the experiment. The experiment has shown that significant strength and stiffness improvement can be obtained at large-scale using conditions and equipment similar to those expected in potential applications. In this study unconfined compressive strength was shown as high as 12.4MPa at 2137kg/m^3 density. The calcite content was as high as 25% of dry weight. The result of this study in 2010 has served as an important benchmark for future applications of biomediated ground improvement.

III. EXPERIMENTAL PROCEDURE

Laboratory column tests were conducted using plant derived urease to induce calcium carbonate precipitation in Ottawa 20-30 silica sand and F-60 silica sand. Tubes were filled with approximately 100ml of a well-mixed pH=8.75 solution containing 1.38M urea, 1.58M calcium chloride dehydrate. Two types of columns were prepared, mixed and compacted column, injected column. The first types of columns were prepared by mixing with the fluid in the tubes and were lightly compacted using vibration. The 20-30 silica sand had an approximate unconfined compressive strength of 529kPa and F-60 silica sand had a peak unconfined compressivestrength of 391kPa. 1.8% of calcite content was being observed in this test. Acid digestions of approximate half-sections from mixed and compacted columns indicate that calcium carbonate ranged from 2.8% to 4.3% (w/w). The injected column that received bentonite slurry was acid digested and had a calcium carbonate content of approximately 1.8%. Cemented sand columns developed in these experiments showed substantial unconfined compressive strength indicating that EICP may potentially be used to form columns of improved soil via calcium carbonate precipitation.

3.1 Acid Digestion:

Acid Digestion is used to determine calcite content precipitated in soil. 1M HCl is used in this process. Digestion was accomplished by oven drying the specimen for 48 hours, weighing, and reweighing the specimen.

Fig 2. Acid Digestion process to determine Calcite Conte

TABLE 1

S.No.	Property of Sand	Value
1.	Mean Specific Gravity	2.82
2.	IS Classification	SW
3.	Minimum Dry Density	1.39 gm/cc
4.	Maximum Dry Density	1.66 gm/cc
5.	Minimum Void Ratio	0.62
6.	Maximum Void Ratio	0.72

IV. CONCLUSION

Sand column tests show the use of agriculturally derived urease. In MICP technique the main problem is maintaining a bio reactor at site which is solved by EICP technique. In EICP columns cementation is induced due to calcium carbonate precipitation. The range of calcium carbonate precipitation is 2.8-4.3%.

This technique is very useful for fugitive dust mitigation. Hence EICP technique has a bright future in geoenvironmental engineering.

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