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ENZYME INDUCED CARBONATE PRECIPITATION COLUMNS: STRENGTH AND PERMEABILITY PROPERTIES

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ABSTRACT

Enzyme induced carbonate technique is a new technique in geoenvironmental engineering. It can serve as a grout in cracks of dams as well as in desert areas to combat wind erosion. It improves shear strength properties of soil by introducing cohesion in sand. In this paper the results of EICP columns on different parameters such as strength, permeability are presented. Initially columns were constructed by Calcium Chloride Dihydrate, Urea, Water, Urease enzyme and skimmed milk solution with a pH of 7.23 at 17.3℃. Some amount of sodium hydroxide was added to maintain the pH of solution. After 28 days the soil columns were removed from the PVC pipes and tested for permeability, compressive strength, and direct shear test. Cementation was observed after 28 days and acid digestion was done in order to measure the percentage by weight of calcium carbonate. A sharp decrease in permeability was observed in silica sand which was highly permeable before injection of EICP solution due to its large particle size. The cohesion property induced in sand due to the EICP solution was revealed by Direct Shear Test. A maximum value of cohesion 19.613Kn/m^2 was found in injected silica sand. Using Hydrolysis of Urea with Calcium Chloride Dihydrate can modify soil properties and is a significant step in doing bio modification of soils economically.

***Keywords:* Cementation, compressive strength, EICP Columns, permeability.**

I. INTRODUCTION

A few researchers have focused on this Enzyme Induced Carbonate Precipitation technique. Precipitation of calcium carbonate in soil can decrease its permeability, increase its shear strength and increase its cementation property. A similar technique like EICP is Microbially Induced Carbonate Precipitation (MICP). The basic difference in between these two techniques is the nature of urease enzyme. In EICP technique plant derived urease enzyme (which is produced in laboratory) is used whereas in MICP technique in situ cultivation of microorganisms is done. There are certain advantages of EICP over MICP. One is production of plant derived urease in laboratory so the quality control will be good. Second, there is no need to maintain onsite bioreactor which is very difficult in areas of huge population. Another advantage of EICP over MICP is it does not produce ammonium ion as a waste product in MICP. But EICP technique is new so there is a need to derive an optimum concentration of chemicals so as to convert this technique as an eco friendly as well as cost effective in terms of

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geotechnical properties. A number of different concentration solutions for EICP technique have been tried by Edward Kavazanjian and Nasser Hamadan in 2015. In this paper the effect of carbonate precipitation on different properties of soil is described.

II. OVERVIEW OF EARLIER RESEARCH

Less number of research works has been done on the EICP technique. In this technique laboratory prepared urease enzyme is directly induced in the soil without cultivating it as in MICP. In 2015 Edward Kavazanjian and Nasser Hamadan have conducted strength experiments on silica sand columns. In their work carbonate precipitation was about 2.8-4.3% by weight of soil with an unconfined compressive strength of 425kPa to 529kPa. In 2014 Brian Knorr and Edward Kavazanjian used this technique for the mitigation of fugitive dust to control health hazards as well as erosion problems in desert areas. They tried to lessen the concentration by limiting it within 1M solution. Earlier to this Nasser Hamadan and Kavazanjian in 2013 have conducted erosion control researches at Arizona state university creating 13 samples of native Arizona silty sand. They tried with 0.3M, 1M and 2M of calcium chloride and urea solutions. They tested the soil samples on varying wind speed. They focused their research work on strength as well as permeability of soil. M.G. Gomez with J.T. Dejong in 2014 examined the effect on permeability as well as unconfined compressive strength on eight different river sands by MICP technique. By MICP technique they got unconfined compressive strength of different sands in range of 1.07MPa- 5.34MPa whereas permeability k_{final} /$k_{initial}$ value of 0.0003-0.4078. By this work it was clear that on different sands the effect on properties by MICP was also different.

There is less number of literatures on EICP technique and some have focused on unconfined compressive strength as well as wind erosion separately. Studying the effect of EICP solution on same soil with a number of properties such as unconfined compressive strength, permeability in coarse silica sand and fine sand was not done collectively.

The aims of this paper are therefore 1.To study the bio clogging mechanism in two different soils presenting different grain size distributions:- coarse silica sand and fine kurukshetra local sand , 2. To study the effect of less concentrated EICP solution than previous works on different properties of soil. Tests were carried out in columns of soil with decrease in concentration of EICP solution and with a decreased pH value of solution which is near to normal water pH so as to see variations on soil properties with decrease in pH of solution. The focus of this work is to run the experiment in a natural environmental condition not in a specified laboratory such as environmental varying temperature. In earlier works the researchers have maintained constant temperature which will create a lot of problem on site.

II. MATERIALS AND METHODS

The materials used in this study are silica sand and local kurukshetra fine sand. The properties of both are mentioned in table 1 as under.

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Table 1

Type of soil	C_u	C_c	**Specific Gravity**	e_{max}	e_{min}	**Maximum dry density(g/cm^3)**	**Minimum dry density(g/cm^3)**
Silica Sand	2.5	0.597	2.82	0.72	0.62	1.66	1.39
Local Kurukshetra Sand	2.045	1.067	2.69	0.71	0.61	1.65	1.40

Here silica sand has D_{60}=0.45mm, D_{30}=0.22mm, D_{10}=0.18mm whereas local kurukshetra sand has D_{60}=1.8mm, D_{30}=1.3mm, D_{10}=0.88mm.

3.1 Mixed & Compacted Column

The tests were carried out in Polypropylene coated 6 inches length and outer diameter 2 inches clear PVC pipes. The PVC pipes were of class-2 grade IS 4985 standard. A polypropylene circular section exactly matching the bottom surface area of the PVC tube was placed at the bottom of the column and closed off with a rubber cap. A polypropylene lining was done in order to make the column perfectly leak proof so that no solution escapes from the bottom of column when it is in erect position.

Fig 1. Silica Sand Column

Column 1 was filled with approximately 250ml of a well-mixed solution (pH=7.23) containing 0.75M urea, 0.5M calcium chloride dihydrate, 0.50g/l urease enzyme, 4.0g/l stabilizer(non-fat dry skimmed milk). Approximately 1200.3gm, 1202.67gm of silica sand and local kurukshetra sand was poured into columns 1 and 2 respectively. The soil was mixed with the solution in the pipes and lightly compacted using vibration (1 minute 30 seconds).

IJARSE
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Fig 2. Top view of Local Sand Column with PVC pipe

3.2 Injected Columns

Two PVC columns 6inches long and outer diameter 2inches were taken and labeled as col3 and col4. The bottom end of PVC column was closed by rubber and polythene. The columns were filled with sand to a depth of approximately 3inches. Then densification was done via firm tapping along the curved surface area of column using a blunt object. Due to decrease in depth of each sand layer, extra amount of sand was added in both the columns. It was done to maintain the depth of each layer of sand. Next a perforated injection tube of ¼ inch outer diameter containing 16-18 radial holes was kept vertically in PVC columns. Soil was filled up to 6inches height in the columns. Silica sand was used in column 3 and local sand was used in column 4. Column 3 contained 1426.83g silica sand and column 4 contained 1313.9g of local sand. 250ml of reaction medium(pH=7.23, 16.8℃) was added to each column consisting of 0.75M urea and 0.5M calcium chloride dihydrate in tap water. The injection tubes were flushed and followed by 50ml of enzyme solution consisting of 0.50g/l urease enzyme and 4.0g/l stabilizer.

Finally all four columns were left in environmental condition (temperature range 16℃- 30℃) for 28days. In all the four columns lubricant was used at the start of the experiment so that the soil column can come out easily from the PVC pipes. After 28days all the four soil columns were removed carefully. Though detachment of soil columns was done carefully but in local sand columns irregular shape and braking of some parts was observed. Hence only silica sand columns were tested in order to check their compressive strength whereas specimens from all four columns were taken to conduct direct shear test. Cementation was observed in the entire specimen. This was confirmed by direct shear test which showed cohesive nature induced due to carbonate precipitation in sand. Acid digestion by 2M hydrochloric acid solution was done to get calcium carbonate percentage precipitated in soil. After compressive strength test and direct shear test the four specimens along with parent soil specimens were checked for permeability. This permeability test showed a good amount of imperviousness induced due to carbonate precipitation in soil.

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Fig 3. Top view of Silica sand column

VI. RESULTS

On four soil columns compressive strength test, direct shear test, acid digestion test and permeability tests were performed to check the behavior of soil after mixing solution in it.

4.1 Compressive Strength Test

Local sand columns were broken while taking out from the PVC tubes, so compressive strength test was done only on silica sand columns. At 0.91% axial strain on mixed & compacted column it showed 198.4kPa whereas at 0.80% axial strain on injected column it showed 165.33kPa compressive strength.

4.2 Acid Digestion

Acid digestion was done on all four samples using 2M HCl to determine calcium carbonate percentage. It showed 3.2% in mixed & compacted column whereas 2.7% in injected column.

4.3 Direct Shear Test

The different values of c and φ determined from the direct shear test are mentioned in Table 2 as under.

TABLE 2

Type of soil	**C (kN/m$^{2)}$**	$\boldsymbol{\varphi}$
Parent Silica Sand (without any treatment	0	32^o
Mixed & Compacted silica sand	9.8065	37^o
Injected silica sand	19.613	36^o
Local silica sand (without any treatment)	0	32^o
Mixed & compacted local sand	19.613	33^o
Injected local sand	7.8452	32^o

The shear strength under different values of normal stress = 50, 100, 150 kN/m^2 are mentioned in table 3.

IJARSE
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TABLE 3

Type of soil	**Shear strength at normal stress = 50kN/m²**	**Shear strength at normal stress = 100kN/m²**	**Shear strength at normal stress = 150kN/m²**
Parent Silica Sand (without any treatment	31.24	62.487	93.73
Mixed & Compacted silica sand	47.484	85.162	122.84
Injected silica sand	55.94	92.267	128.594
Local silica sand (without any treatment)	31.24	62.487	93.73
Mixed & compacted local sand	52.08	84.55	117.024
Injected local sand	39.088	70.332	101.575

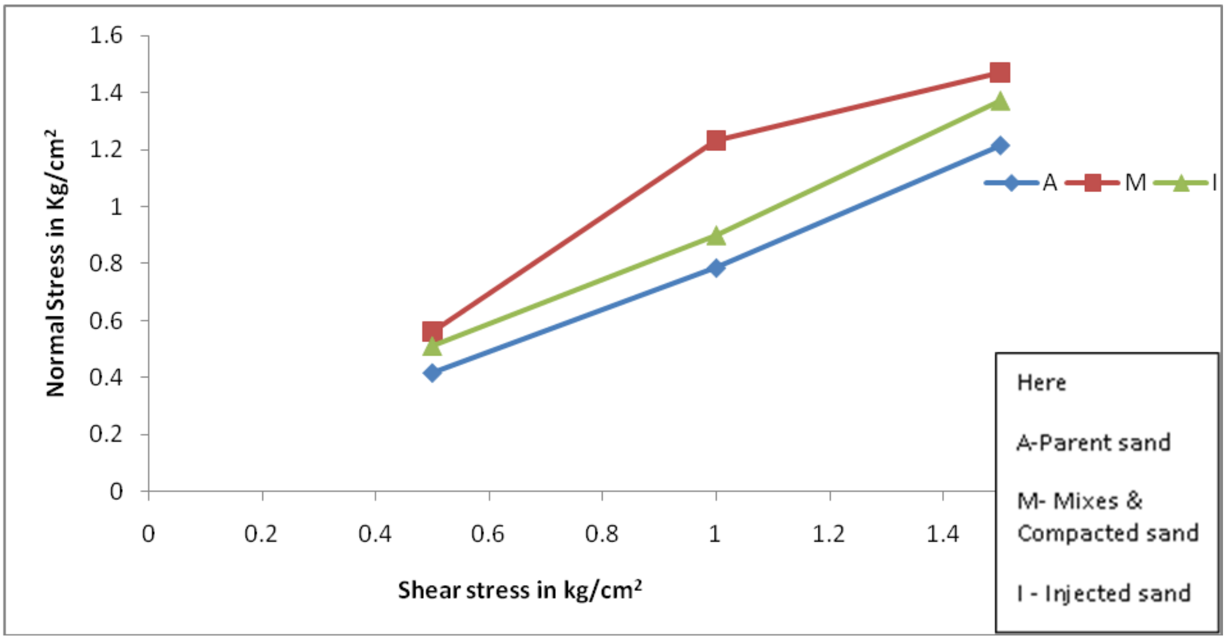

Fig 4. Normal Stress vs. Shear Stress via Direct Shear Test for Local Sand

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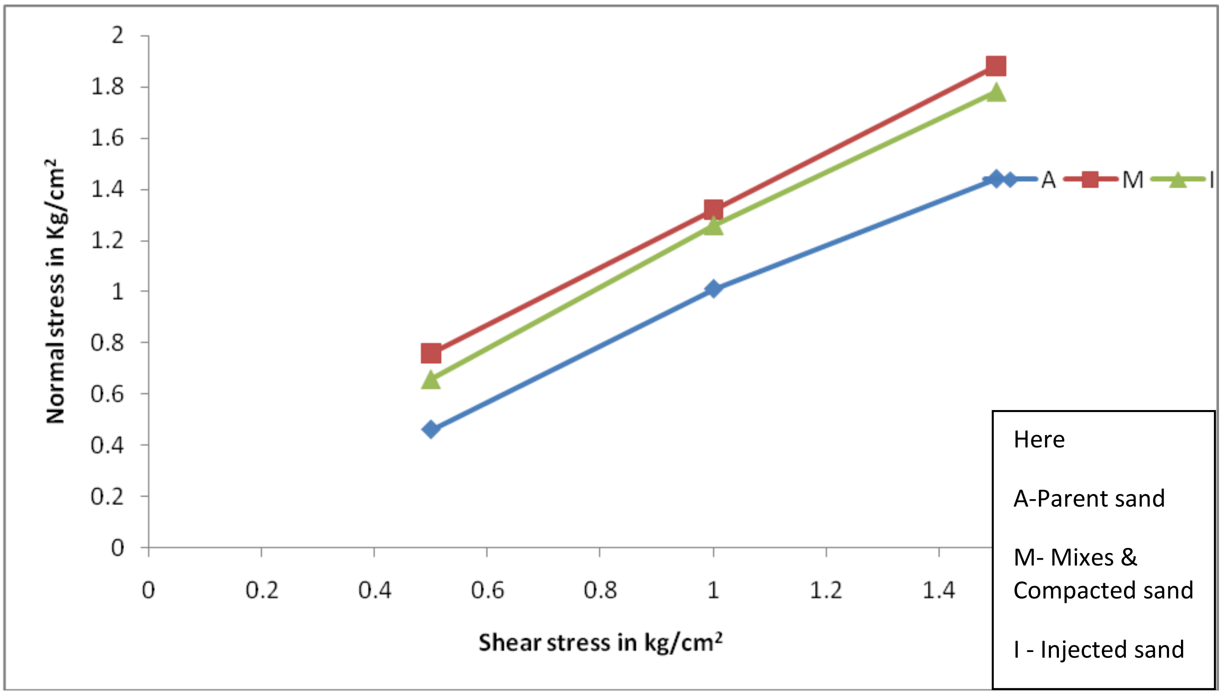

Fig 5. Normal Stress vs. Shear Stress via Direct Shear Test Silica Sand

4.4 Permeability Test

Permeability test results for both untreated and treated samples are shown in table 4 and table 5.

TABLE 4

Sand Specimen	**$k_{initial}$ (mm/sec)**	**k_{final} (mm/sec)**	**Decrease in Permeability Or $k_{initial}/k_{final}$**
Silica Sand	12.24E-03	2.088E-03	5.859 times
Local Sand	7.98E-03	3.869E-03	2.0625 times

Table: 5

Sand Specimen	**$k_{initial}$ (mm/sec)**	**k_{final} (mm/sec)**	**Decrease in Permeability Or $k_{initial}/k_{final}$**
Silica Sand	12.24E-03	1.3355E-03	9.165 times
Local Sand	7.98E-03	1.35E-03	5.911 times

From the above tabulated results it is clear that maximum decrease in permeability is observed in silica sand by injection method. Approximately 9 times decrease in permeability has been recorded whereas by mixed & compacted method 6 times decrease in permeability is seen. In local sand by injected method 6 times decrease whereas by mixed & compacted method 2 times decrease has been observed. Hence in order to decrease permeability, injected method is better than mixed & compacted.

IJARSE
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V. CONCLUSION

Calcium Carbonate precipitation was successfully completed with the help of urease enzyme by two different methods: - 1.Mixed & Compacted method, 2.Injected method. Compressive strength was better in mixed & compacted method than injected method. In mixed & compacted method it was 198.4kPa whereas in injected it was 165.33kPa. Calcium Carbonate precipitation was slightly good in mixed & compacted as compared to injected e.g.:- 3.2% over 2.7%. By direct shear test it is clear that in both the methods cohesion value ranged from 7.8452kN/m^2 to 19.613kN/m^2. This was the reason of cementation in sand columns. Shear strength property of sand was also improved due to carbonate precipitation. By permeability test this experiment showed two times to nine times decrease in permeability. Highest decrease in permeability was observed was observed in injected silica sand column. Injected method was better in terms of decrease in permeability. These results showed that Enzyme Induced Carbonate Precipitation technique can be potentially used to improve different properties of soil such as:- compressive strength, shear strength, permeability etc.

VI. ACKNOWLEDGEMENT

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