STUDY ON EFFECT OF MICROBIAL INDUCED CALCITE PRECIPITATES ON STRENGTH OF SOIL

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Abstract : The challenges to strengthen the weak soil always prompted the need for further research investigation to develop a new, eco-friendly and sustainable method of soil stabilization. One possible technique is Microbial-Induced Calcite Precipitation (MICP) which has recently emerged as a sustainable technique for soil improvement. This study focuses on bacterial calcium carbonate precipitation and its effect on the compressibility and strength of soil. Two different types of soils (high plastic clay and low plastic clay) were used for the study. A species of Bacillus group B.megaterium (MTCC-428) was used to activate and catalyze the calcite precipitation caused by reaction between urea and calcium chloride. MICP uses bacteria to hydrolyses urea and give carbonate ions which react with a calcium chloride solution to produce calcium carbonate (calcite) that binds the soil particles together leading to increased soil strength and stiffness. Nutrient delivery system was use to induce cementation reagents. Variable parameters such as concentration of cementation reagent (0.25M, 0.50M, 0.75M, 1M) and curing period (1day, 3day, 7day) were studied. These parameters were applied on both the type of soils in specified duration and range to utilize the effect of MICP. From the results there were perceived improvement (1.15-2 times) in unconfined compressive strength in both the type of soils. It was also found that the strength increased with increment in treatment duration.

***IndexTerms* - Soil stabilization; Calcite precipitation; B.megaterium; Unconfined compressive strength;**

I.INTRODUCTION

The need for stabilizing soils becomes necessary mainly because of two reasons: i) weak or inconsistent soil properties and ii) need for urbanization especially in areas with problematic soils. It is believed that the demand for new and sustainable soil stabilization techniques, continues to grow with more than 40,000 soil stabilization projects being carried out worldwide with total costs exceeding US$ 6 billion/year. The artificial cementation of soil particles due to soil stabilization is often achieved through the use of chemical stabilizers via shallow and deep mixing or injecting chemical grouts that can permeate through soils. Physical properties of soil can be modified by the use of mechanical compaction or compaction grouting while chemical properties of soil can be modified by the use of chemical stabilizers such as Portland cement, lime and fly ash. Mechanical compaction is recommended for sandy soils and is effective or economical to a depth less than 10 m (Ivanonv & Chu, 2008). Chemical stabilization is typically recommended for expansive soils (Petry & Little, 2002). Environmentally safe techniques such as pre-wetting and moisture barriers are only possible for small confined spaces, and are not suitable for larger construction projects such as highways and railways which spread for miles. Traditional ground improvement methods have several limitations. The action radius is limited to the proximity of the mixing equipment. High pressures are often required to inject the grouts due to their high viscosity or fast hardening time. Freezing is only a temporal solution during construction. Next to that most of these methods are expensive, require heavy machinery, disturbing urban infrastructure and involve chemicals with significant environmental impact. Consequently, these conventional methods are not suitable for treating large volumes of soil As mentioned above, artificial cementation techniques are not always feasible and environmentally friendly. However, reduction in the use of artificial cementation techniques can be practiced by substituting with environmental friendly techniques or materials.

One such method of soil stabilization technique is, Microbial Induced Calcite Precipitation (MICP). MICP technique is considered to be a better and more environmentally friendly alternative to the conventional technologies. This technique employs microbes as a primary factor for stabilization. Calcium carbonate precipitation has been induced inside the soil matrix by microorganism through their metabolic process to improve the engineering properties of soil. Hence, this technique is called as microbial induced carbonate precipitation or MICP. Successful implementation of MICP will have its application in a wide variety of civil engineering fields such as stability of retaining walls, embankments and dams, controlling soil erosion, stabilizing cohesion less soils to facilitate the stability of underground constructions, increasing bearing capacity of shallow and piled foundation and reducing the liquefaction potential of soil.

II.THEORETICAL BACKGROUND

Lee Min Lee et al. (2012) studied the effect of MICP (Lee Min Lee et al., 2012) on shear strength and reducing hydraulic conductivity of soils. The results showed that MICP could effectively increase the shear strength and reduce hydraulic conductivity of soils. In general, MICP can be achieved by urea hydrolysis, aerobic oxidation, de-nitrification, sulphate reduction, etc. Van Paassen et al. (2010) suggested that urea hydrolysis pos-sesses the highest calcite conversion rate compared to other studied processes (Harkes et al., 2010; Whiffin et al., 2007).Urea hydrolysis refers to a chemical reaction where urea ($CO(NH_2)_2$) is decomposed by Urease enzyme that can be either supplied externally (Greene et al., 2003), or produced in situ by Urease producing microorganisms (DeJong et al., 2006). The latter process requires Urease positive type bacteria, i.e. genera Bacillus, Sporosarcina.

1 mole of urea decomposes into 2 moles of ammonium according to following reaction:

$$CO(NH_2)_2 + 2H_2O \rightarrow 2NH^{4+} + CO_3^{2-} \quad \text{\_\_\_\_\_\_\_\_} \quad (1)$$

The release of ammonium (NH4+) cause increase in pH, which in due course, creates a perfect circumstance for calcite precipitation with the availability of calcium ion(Ca^{2+}) from the supplied calcium chloride:

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3 \quad \text{\_\_\_\_\_\_\_\_} \quad (2)$$

The $CaCO_3$ precipitates formed are gelatinous in nature and thus helps in bonding the soil particles together.

III.MATERIAL AND METHODOLOGY

3.1 Soil Characteristics

Two types of soils were considered for this study. Both soil samples were collected from Dholera (Gujarat, India).The basic properties of the collected samples and soil classification are in Table 1. These samples were treated with bacteria and cementation reagent and then tested for strength increment.

The Properties of materials that are obtained from the laboratory tests are:

Table1 Properties of soil

Sr no.	Test	Symbol	Result Soil (S1)	Result Soil (S2)	IS Code
1	Liquid Limit	LL	54%	35%	IS 2720 (Part 5)-1985
2	Plastic Limit	PL	26.57%	26.19%	IS 2720 (Part 5)-1985
3	Plasticity Index	PI	27.43%	8.81%	IS 2720 (Part 5)-1985
4	Soil Classification	-	CH	CL	IS 1498-1970
5	Shrinkage Limit	SL	22.59%	10.76%	IS 2720 (Part 6)-1978
6	Specific Gravity	G	2.71	2.64	IS 2720 (Part 3)-1980
7	Free Swell Index	FSI	14.5%	10.5%	IS 2720 (Part 40)-197
8	Hydrometer	Clay Silt	40% 56%	17% 61%	IS 2720 (Part 4)-1985
9	Standard Proctor Test	OMC MDD	23.0 % 1.59 gm/cc	19.0% 1.73 gm/cc	IS 2720 (Part 7)-1980
10	pH	_	8.83	8.54	IS 2720 (Part 10)-1991
11	Unconfined compressive strength	q_u	178.63 kPa	104.05 kPa	IS 2720 (Part 26)-1987

3.2 Activation and Cultivation of Bacteria

Bacterial strain bacillus megaterium (MTCC-426) is used for this research was ordered from microbial type culture collection and gene bank (MTCC) Chandigarh in freeze dried condition. freeze dried culture was taken in a petri plate which was previously solidified with agar. Which is incubated at -4˚c temperature and under condition recommended for the culture. The growth media used to grow the microorganisms was primarily nutrient broth (NB).

(a) (b) (c)

Fig.1. (a) Freeze dried culture (b) & (c) Activated culture on Petri plate

Microbial concentration tests were used in this research to determine the effect of microbial concentration in evaluating the effect of MICP in soils. In order to maintain the consistency of microbial concentration throughout the research, colony formation unit (CFU) method was adopted to determine the concentration of microbes in a given solution. After 48 hours of incubation, the optical density (OD) of these cultured microbes was measured. OD is the method of determining concentration of microbes in a sample by measuring the turbidity of the sample at certain wavelength, usually 600 nm. These cultured microbes were then serially diluted and After serial dilution, 10ml of the serial diluted media was taken and then plated in a NB plate. (NB plate was prepared by mixing 10 g of LB and 6 g of agar in 400 ml of distilled water. The media after autoclaving was poured into the petri dish. The media solidifies after few hours due to the presence of agar.) after 48 hours of plating, the number of colonies were counted. The CFU/ml for each serial dilution is given as per Equation.

$$\text{CFU/ml} = \frac{\text{No.of colonies counted} \times \text{Dilution factor}}{\text{Volume of culture}}$$

3.3 Cementation reagent

Cementation reagent serves as important ingredients for promoting calcite precipitation. As shown in equations (1) and (2), the ammonium (NH^{4+}) and calcium (Ca^{2+}) ions are decomposed from urea ($CO(NH_2)_2$) and calcium chloride ($CaCl_2$), respectively. It is thus important to supply sufficient amount of urea and calcium chloride into the soil. The cementation reagent also contained 3 gm nutrient broth, 10 gm NH_4Cl, and 2.12 gm $NaHCO_3$ per liter of water.

3.4 Laboratory Setup

Fig. 2(a) shows the schematic diagram of the laboratory setup. The test is carried out in a prefabricated mould, which has the provision of inlet and outlet and control of flow. The apparatus is of a split type acrylic mould of 90 mm internal diameter (ID) and 160 mm height. The setup consists of a reagent tank, prefabricated mould, inlet and outlet valve, and an effluent collector.

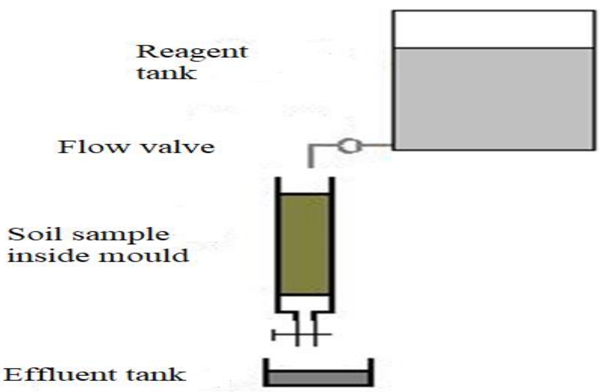


Fig.2. (a) Schematic Diagram of Laboratory Setup

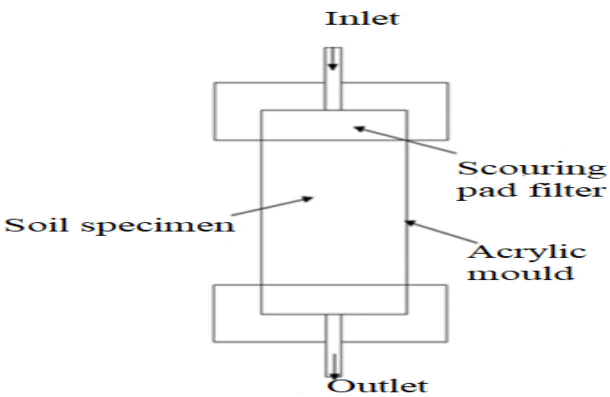


Fig.2. (b) Soil Specimen Mould

3.5 Preparation of soil specimen

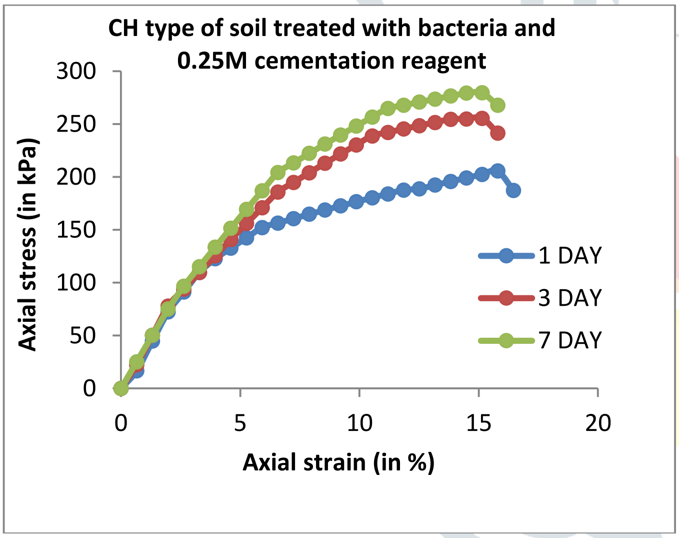
Initially, bacteria was added to the soil and mixed properly. Soil was compacted at 95% of MDD and respective OMC prior to treatment in the prefabricated mould. Since treatment duration was a parameter, soil samples of given molar concentrations were allowed for curing duration of 1, 3 and 7 days. For everyday treatment, 1litre of nutrients are allowed to pass through the sample. Upon the completion of the treatment, the soil was extruded from the acrylic mould and tested for its shear strength through the unconfined compression test.

3.6 Experimental Variables

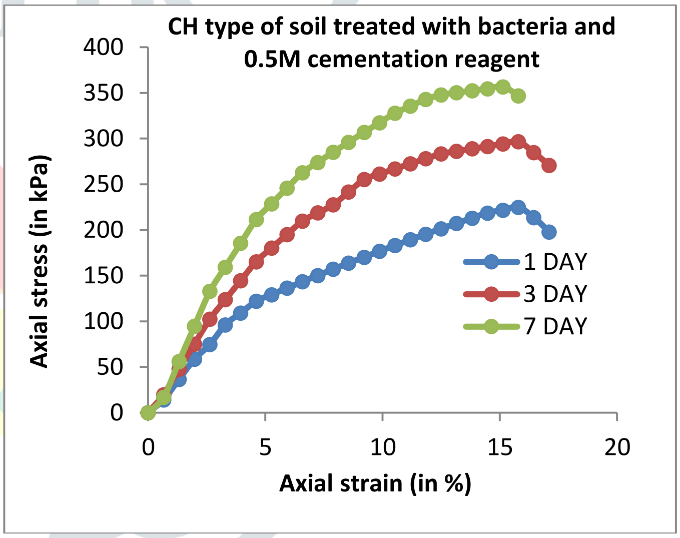
Two different types of soils were used for these study .The main variable in this study was the concentration of cementation reagent and curing period. Four concentrations were adopted, i.e. 0.25 M, 0.5 M, 0.75M, and 1 M. Three parameters were selected for curing period, i.e. 1 day, 3day and 7 day.

IV. RESULT AND DISCUSSION

The stress strain curves of all the soil specimens tested in the unconfined compression testing machine are shown in figures. The UCS value for virgin soil sample 1(CH Soil) was 178.63 kPa, which on treatment with MICP was found to increase further. The test results of soil sample 1(CH Soil) are tabulated in Table 2. It was observed from the test results that by increasing the treatment duration, UCS values further increased. For soil sample 1(CH Soil), highest increment was observed for molar concentration of 0.5 M of cementation reagent. UCS value further increased on increasing the treatment duration. The test results of soil sample 2(CL Soil) are tabulated in Table 3. Higher bond formation in soil then lead to increase in cohesion of soil which is one of the parameters for the soil's shear strength and hence increase in soil strength.



(a)



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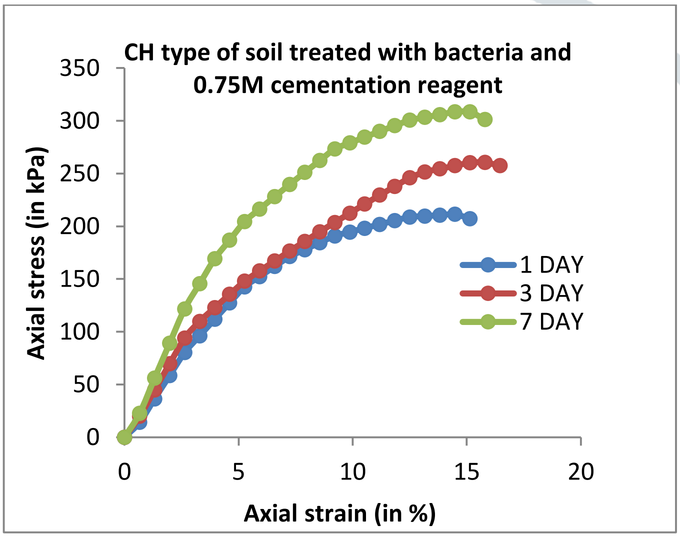

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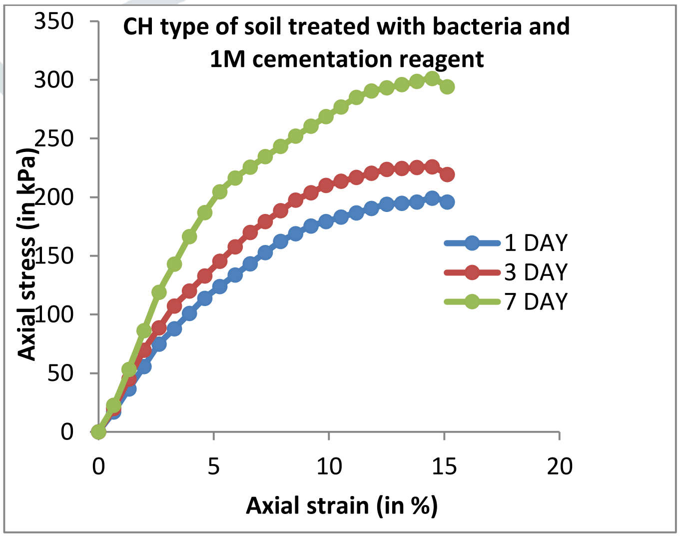
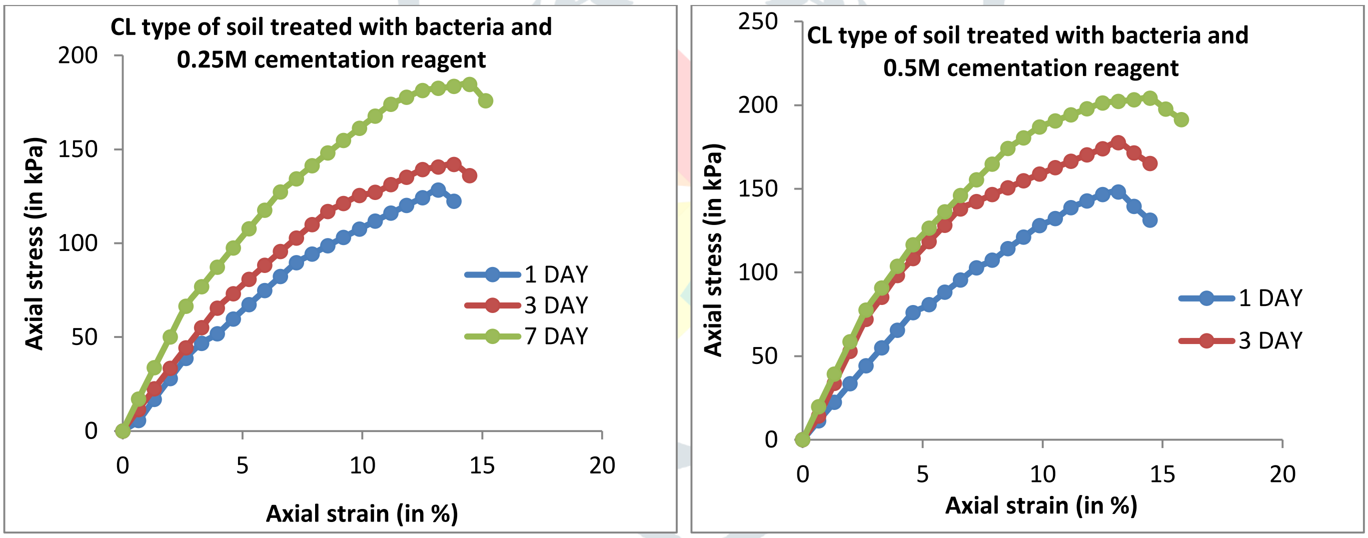


(d)

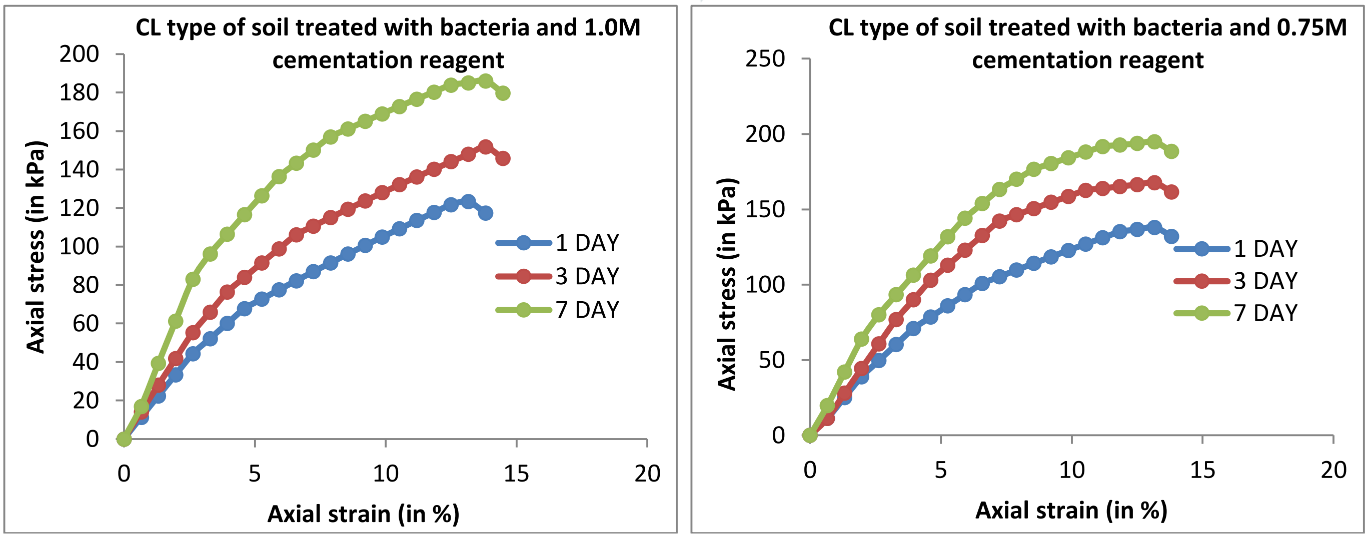
Fig.3.Soil S1 (CH) treated with bacteria and (a) 0.25M (b) 0.5M (c) 0.75M (d) 1.0M cementation reagent

Table 2 Strength of Soil 1 (CH) soil after treatment

		Soil 1 (CH) Unconfined Compressive Strength (kPa)			
Bacteria	Cementation reagents	Untreated	1 day	3 day	7 day
Bacillus Megaterium 1×10^8 CFU/ml	0.25 M	178.63	205.66 (1.15 times)	255.47 (1.43 times)	279.59 (1.56 times)
	0.50 M	178.63	224.79 (1.25 times)	296.54 (1.66 times)	356.70 (1.99 times)
	0.75 M	178.63	211.31 (1.18 times)	260.67 (1.46 times)	308.50 (1.25 times)
	1.0 M	178.63	199.16 (1.11 times)	225.88 (1.26 times)	301.78 (1.69 times)



(a) (b)



(c) (d)

Fig.3.Soil S2 (CL) treated with bacteria and (a) 0.25M (b) 0.5M (c) 0.75M (d) 1.0M cementation reagent

Table 3 Strength of Soil 2 (CL) soil after treatment

		Soil 2 (CL) Unconfined Compressive Strength (kPa)			
Bacteria	Cementation reagents	Untreated	1 day	3 day	7 day
Bacillus Megaterium 1×10^8 CFU/ml	0.25 M	104.05	128.24 (1.23 times)	141.96 (1.36 times)	184.59 (1.77 times)
	0.50 M	104.05	147.97 (1.42 times)	177.57 (1.71 times)	204.02 (1.96 times)
	0.75 M	104.05	138.11 (1.33 times)	167.70 (1.61 times)	194.83 (1.87 times)
	1.0 M	104.05	123.3 (1.19 times)	151.75 (1.46 times)	186.01 (1.78 times)

V.CONCLUSION

Based on the experimental results the following conclusions can be drawn:

- MICP was found to increased the unconfined compressive strength of both the CH and CL type of soils (1.15 to 2 times).
- It was also observed that strength increased with increase in curing duration.
- MICP was found to increase the cohesion of soil. Enhanced strength parameter can be co-related with other properties and possible implications will further lead to increased bearing capacity and reduced permeability of soil
- MICP was found to increase the cohesion of soil. Strength parameter can be co-related with other properties of soil and possible implications will further lead to increased bearing capacity, reduced permeability of soil.
- MICP can be cost effective as it can be produced in larger quantity at a very low price. Bacterial solution can be prepared in huge amounts at very low costs and cementing reagents also are very economical compared to other soil improvement techniques.

VI.ACKNOWLEDGMENT

The authors are highly thankful to Prof. (Dr.) G. P. Vadodariya, principal, L D College of Engineering for providing all necessary research facilities.

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