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Study on Effect of Enzyme Induced Calcite Precipitation in Fine-grained soil

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Abstract: When the natural soil cannot satisfy engineering requirements, soil improvement is regarded as a substitute. One of the most common methods for improving the soil in the past was to add cement or lime. There are numerous customised soil improvement methods accessible today. While some treatments are difficult to apply, others are not ecologically friendly. The development of alternatives to mechanical and chemical stabilisation for soil has led to the emergence of bio-stabilization approaches. Enzymes are frequently involved in the bio-stabilization process, which promotes ureolysis and causes calcite to precipitate in the soil mass. Recent studies on sustainable ground improvement techniques suggest that Enzyme Induced Calcite Precipitation (EICP) is a good choice for soil development.Soil sample was silty clay with liquid limit 69%, plastic limit 28.3%, and plasticity index of 40.7%. Soil has an undrained shear strength of 25.4 kPa. By using 2.5 g/l urease enzyme concentration, the liquid limit and plasticity index of the sample decreased by 20.3% and 51.4% respectively and plastic limit of the sample increased by 24.4% after 7 days of curing.By using 5 g/l urease enzyme concentration, the liquid limit and plasticity index of the sample decreased by 21.7% and 62.2% respectively and plastic limit of the sample increased by 36.4% after 7 days of curing.
Keywords: Enzyme-induced calcite precipitation, Soil improvement, Calcite precipitation, Soil stabilization

I. INTRODUCTION

Soil stabilisation is crucial when constructing infrastructure in underdeveloped countries or historic cities where site growth is constrained by topography. Construction projects require a solid foundation since it presents significant engineering challenges in addressing human demands (Gitanjali et al., 2024). The goal of soil stabilisation is to increase the soil's bearing capacity while decreasing settlement and deformation (Changizi et al., 2016). Traditional methods for stabilising soil include chemical and mechanical methods. Mechanical stabilisation entails removing air spaces from the soil mass and lowering the water content to the lowest practical level in order to improve performance. Conversely, chemical stabilisation uses chemicals to increase soil strength, decrease permeability, and achieve the desired density (Renjith et al., 2020). The soil is compacted and densified by mechanical techniques such as vibroflotation, rammering, rollers, blasting, and soil preloading. The field implementation of this method may result in significant energy release and high production and installation expenses. The chemical improvement procedure includes grouting and careful mixing of chemical admixtures including fly ash, cement, and lime (Gitanjali et al., 2024). Chemical stabilisation involves the use of silicates, asphalt, Portland cement, polymers, and lime. These changes improve the soil's geotechnical behaviour by changing its chemical composition (Calik et al., 2014).Chemical stabilisation has become popular due to the fact that it improves soil so well; in addition to traditional calcium-based binders such as fly ash, cement, and ash, it can also use novel stabilisers such as lignosulfonates, acids, salts, and enzymes; emulsions, resins, and petroleum-derived polymers can also be used (Tingle et al., 2020). Biologically mediated soil alteration is another new development in soil stability: the domestication of microorganisms to improve soil function; there are many engineering applications for natural mineralisation produced by microorganisms such as fungi, bacteria, and algae (Han et al., 2020). Microbial-induced calcite precipitation (MICP) is a bio-mediated ground improvement technique that uses bacterial invasion to improve the geotechnical properties of soil by binding soil particles together and causing calcium carbonate ($CaCO_3$) to precipitate (Rahman et al.,2020).Among the geotechnical engineering problems that MICP treatment enhances are soil liquefaction, erosion control, carbon dioxide sequestration, shear strength, and contaminated soil rehabilitation. One of the drawbacks of the MICP is the unequal distribution of calcium carbonate (Gitanjali et al., 2024). An innovative and bioinspired method of improving ground is enzyme-induced calcite precipitation (EICP). EICP is a sustainable and ecologically responsible strategy with reduced carbon emissions. Instead of using microbes to precipitate $CaCO_3$, enzyme-induced calcite precipitation (EICP) employs enzymes (Putra et al., 2020). Slope stabilisation, soil scouring reduction, wind and water erosion control, seepage monitoring beneath levees, soil bearing capacity enhancement, tunnelling, and seismic settlement management are just a few of the many engineering uses for this technology (Kavazanjian et al., 2017).

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II. CONCEPT OF EICP METHOD

1) Enzyme Induced Calcite Precipitation

By employing an aqueous chemical solution to precipitate calcite in cavities, the EICP approach enhances the geotechnical properties of soil. By filling the pores and binding and roughening the soil grains, the precipitation makes the soil stronger and more rigid. The EICP approach introduces urease enzymes straight into the soil, while the MICP method uses bacteria to produce urease enzymes. Because bacteria require laboratory equipment to sterilise their surroundings in order to form colonies, using them as living organisms in soil requires a certain environment for their survival. This discovery has the benefit of removing the difficulties associated with using microorganisms to create calcite precipitation (Yousefi et al., 2021). The EICP method employs free urease rather than microorganisms, in contrast to MICP. Microorganisms, plants, and agricultural resources can all create enzymes (Almajed et al., 2018). Based on biological principles, EICP is a new method of ground improvement. EICP is an environmentally beneficial, sustainable, and low-carbon method.

2) Urea Hydrolysis

Using urease enzymes produced by bacteria or derived from plants, EICP catalyses the hydrolysis of urea (Ahenkorah et al., 2021; Almajed et al., 2018). Urea can be changed into ammonium and carbonate anions by the urease enzyme (Eq. (1)). When carbonate anions and external calcium sources are present, the ammonium that is released helps to create an alkaline environment that is favourable for the precipitation of calcium carbonate ($CaCO_3$) (Whiffin et al., 2007). EICP uses the $CaCO_3$ precipitation that comes from the hydrolysis of urea as cementation materials to hold soil particles together and prevent soil erosion. Because the $CaCO_3$ crystals that are principally created have less of an impact on the environmental conditions of the soil matrix, EICP procedures are more ecologically benign than traditional soil stabilisation technologies. High temperature settings, as those seen in arid and semi-arid locations, are more suited for the EICP approach. Purified urease enzyme is expensive for real-world EICP applications (Almajed et al., 2018).

$$CO(NH_2)_2 + 2H_2O \longrightarrow 2NH_4^+ + CO_3^{2-} \quad \ldots\ldots (1)$$

$$Ca^{2+} + CO_3^{2-} \longrightarrow CaCO_3 \quad \ldots\ldots (2)$$

The catalytic mechanism and, consequently, the rate of the reaction or precipitation are determined by the concentration and activity of the urease enzyme. The urease enzyme first hydrolyses urea ($CO(NH_2)_2$) into ammonium (NH_4^+) and carbonate (CO_3^{2-}) ions as part of the EICP process. As a result, the solution's pH likewise increases. These ureolysis products can precipitate carbonate if there are enough divalent cations, such as calcium ions, present. Calcium chloride is one source of calcium ions. In the presence of calcium salt ($CaCl_2$), the solution generates Ca^{2+}, which causes $CaCO_3$ to form.

III. MATERIALS AND TEST METHODS

A. Test Materials

Soil sample was taken close to Neyyar Dam. Jack bean meal was utilised as a source of urease enzyme. The urease enzyme employed in jack bean meal was a firm, light brown powder that dissolves in water. Fig. 1 shows soil sample collected and Fig.2 shows jack bean meal urease enzyme.

Fig. 1 Collected soil sample Fig. 2 Urease enzyme

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Various properties of soil sampleare shown in Table 1.

Table 1: Properties of soil

Property	Value
Natural water content	35%
Specific gravity	2.22
Percentage of clay	45
Percentage of silt	46
Percentage of sand	9
Soil classification	Silty clay
Liquid limit	69%
Plastic limit	28.3%
Plasticity index	40.7%
Undrained shear strength	25.4 kPa

Particle size distribution curve, plasticity chart and stress strain curve are shown in Fig. 3, Fig. 4, Fig. 5.

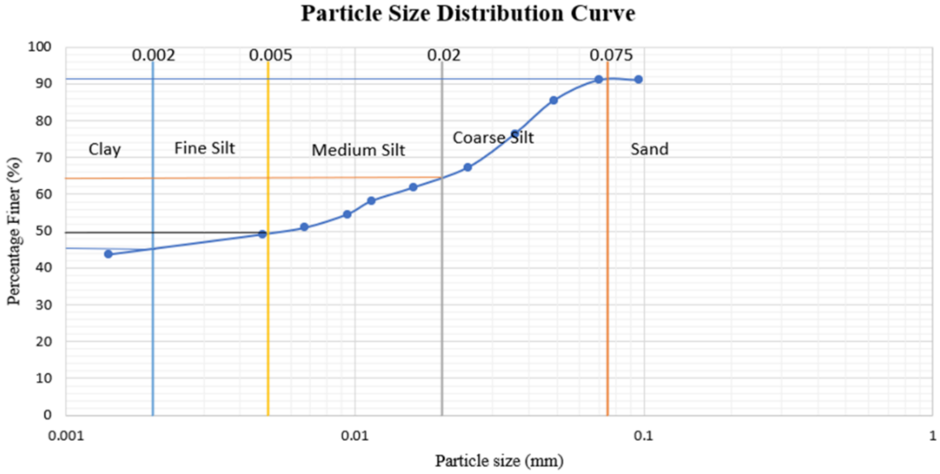

Fig. 3 Particle size distribution curve

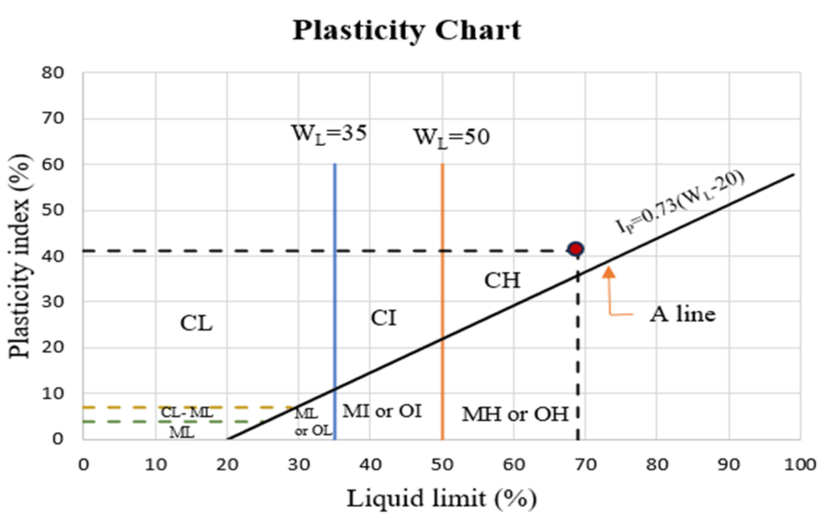

Fig. 4 Plasticity chart

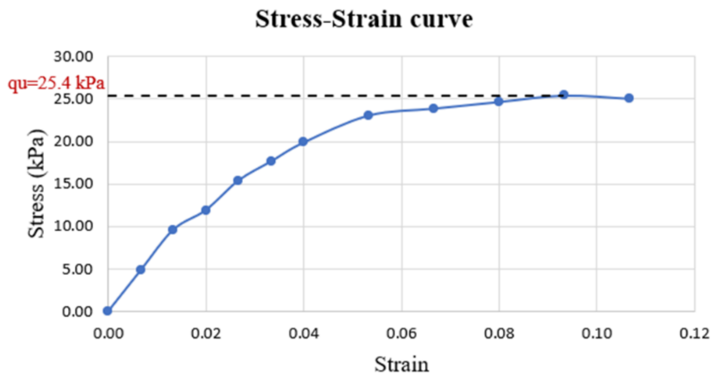

Fig. 5 Stress – strain curve

B. *Test Methods*

Laboratory tests including unconfined compressive strength (UCS) test and plasticity test were performed on untreated and treated samples to study the effects of Enzyme induced calcite precipitationin soil. Soil sample were oven dried.

3.2.1 Preparation of Test solution

In preparation for the EICP treatment, the urease enzyme solution and the urea-$CaCl_2$ solutionalso referred to as the cementation solutionwere made. $CaCl_2$ solution served as the study's Ca^{2+} source. Urea and $CaCl_2$ were combined to create an equimolar cementation solution, with a concentration of 1M (Meng et al. 2021). Since less urea-$CaCl_2$ may result in the presence of excess urea and less mass of calcium carbonate precipitation, and because too much urea-$CaCl_2$ may reduce the efficiency of calcium carbonate precipitation by inhibiting the catalysing capacity of the urease enzyme, equimolar concentration, or 1M, was fixed for the study (Chandra et al. 2021). The components' molecular weights110.9 g of $CaCl_2$ and 60 g of urea, respectivelywere dissolved in one litre of deionised water to produce 1M concentrated urea and $CaCl_2$ solutions. The "Jack bean meal Urease extra pure" enzyme can be utilised for the study because urease from jack bean seeds has been shown to be the most efficient of all plant-derived urease enzymes (Tirkolai et al. 2020).

C. *Effect of EICP in plasticity characteristics*

Variation in properties of Sample treated at 1M cementation solution and 2.5g/l urease concentrationafter EICP treatment for 3 and 7 days of curingis shown in Table 2.

Table 2: Change in plasticity characters after EICP treatment

No. of days of curing	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
Untreated	69	28.3	40.7
Day 3	65	30.5	34.5
Day 7	55	35.2	19.8

Variation in consistency limits of soil after EICP treatmentof 2.5g/l urease concentrationwith a curing of 3and 7 days is shown in Fig.6

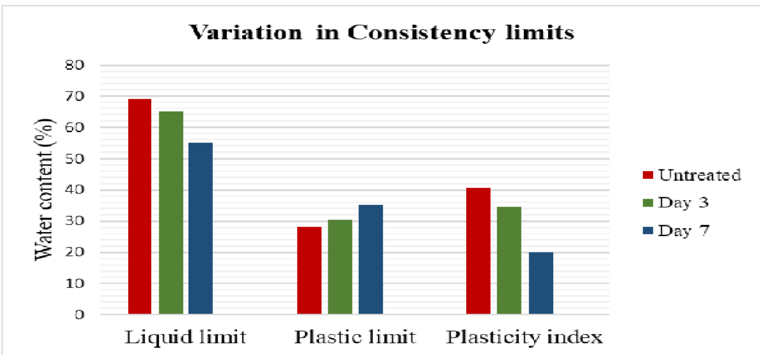

Fig. 6 Variation in consistency limits of 2.5 g/l urease concentration

- Liquid limit and plasticity index of the sample decreased by20.3% and 51.4% respectively with increasing curing time from 0 to 7 days.
- Plastic limit of the sample increased by 24.4% with increasing curing time from 0 to 7 days.

Variation in properties of Sample treated at 1M cementation solution and 5g/l urease concentration after EICP treatment for 3 and 7 days of curing is shown in Table 3.

Table 3: Change in plasticity characters after EICP treatment

No. of days of curing	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
Untreated	69	28.3	40.7
Day 3	63	31.2	31.8
Day 7	54	38.6	15.4

Variation in consistency limits of soil after EICP treatment of 5g/l urease concentration with a curing of 3and 7 days is shown in Fig. 7

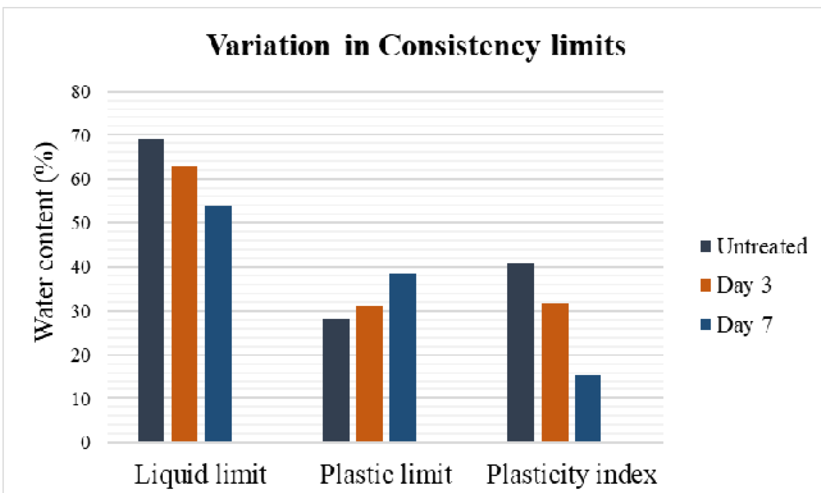

Fig. 7 Variation in consistency limits of 5 g/l urease enzyme concentration

- Liquid limit and plasticity index of the sample decreased by 21.7% and 62.2% respectively with increasing curing time from 0 to 7 days.
- Plastic limit of the sample increased by 36.4% with increasing curing time from 0 to 7 days.

IV. CONCLUSION

1) By using 2.5 g/l urease enzyme concentration, the liquid limit and plasticity index of the sample decreased by 20.3% and 51.4% respectively and plastic limit of the sample increased by 24.4%.
2) By using 5 g/l urease enzyme concentration, the liquid limit and plasticity index of the sample decreased by 21.7% and 62.2% respectively and plastic limit of the sample increased by 36.4%.
3) The increasing concentration of urease enzyme had a positive effect on improvement of plasticity properties of the soil.
4) EICP can be used as an excellent method for the improvement of plasticity characteristic of fine-grained soils.

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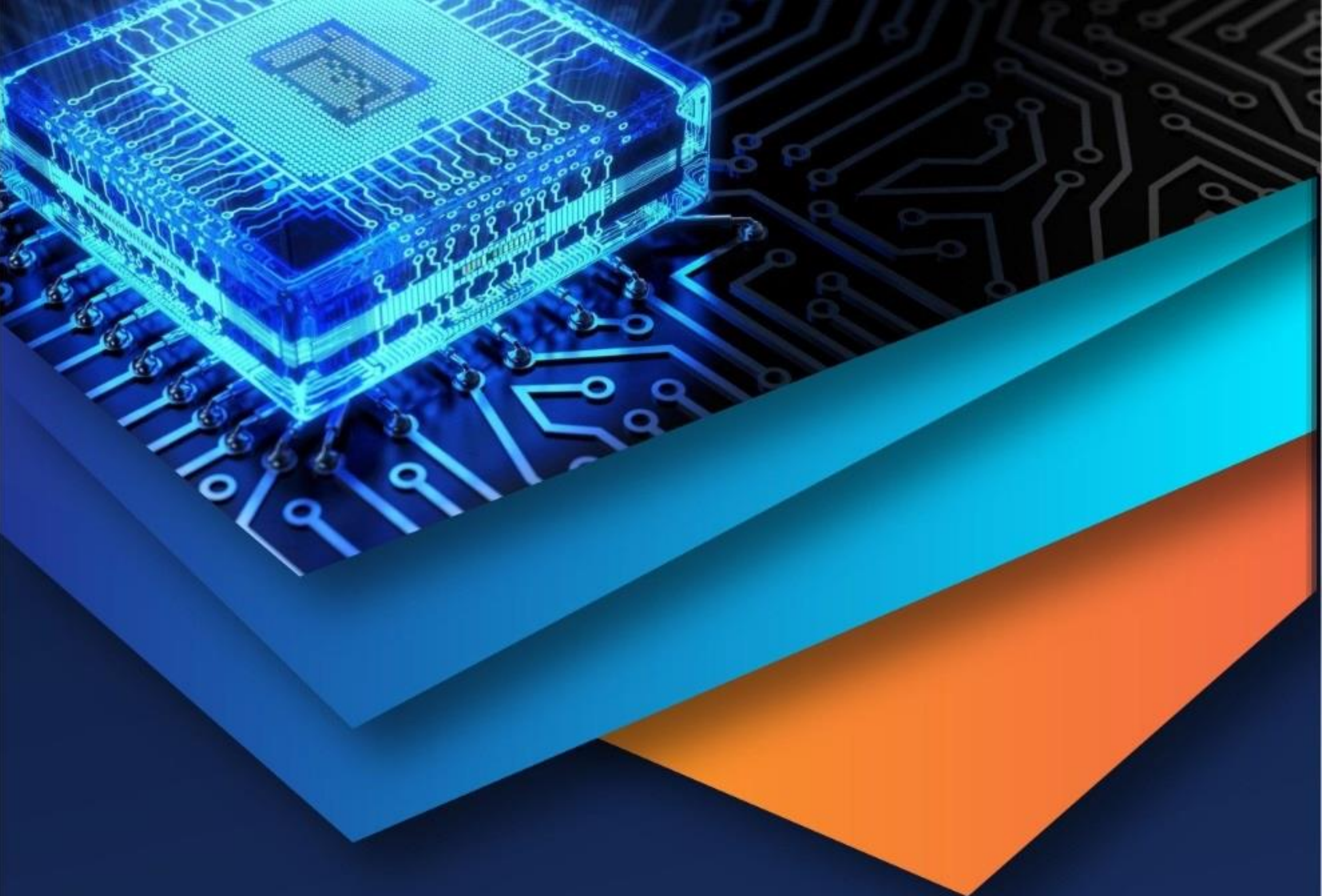

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