A Review on Stabilisation of soil using Biological Soil Improvement Techniques

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***Abstract*— The use of biological processes for ground improvement, particularly bio cementation, is a relatively new area and a potentially sustainable alternative strategy. The most commonly investigated biological soil improvement procedures are Microbially induced calcium carbonate precipitation (MICP) and Enzyme induced calcium carbonate precipitation (EICP). MICP and EICP improve soil by facilitating calcium carbonate precipitation via urease enzymes generated by bacteria cells or plants. Plant derived crude urease enzymes can be used as an excellent alternative to commercially available urease enzymes. A comparative study of the efficiency of both MICP and EICP indicated that EICP can be an excellent alternative to MICP due to its precipitation efficiency ease of controlling the precipitation rate. The results of UCS values of treated EICP samples in different types of soils showed an increase in strength parameters.**

Keywords—MICP, EICP, Crude urease enzyme, Soil improvement, Calcium Carbonate

I. INTRODUCTION

One of the biggest obstacles to infrastructure development is the population expansion within the boundaries of large cities. People have been relocating to the periphery of these sizable cities as a result of the unfavorable ground conditions for the infrastructure. Construction work has been advancing on the challenging and unstable soil, which requires major stabilising. Traditional techniques for enhancing the ground include mechanical stabilisation and grout injection, particularly with cement or polymers. However, the majority of these methods are expensive, demand heavy machinery, disrupt other urban infrastructure, and involve hazardous chemicals with grave environmental consequences. The use of stabilizers such as Portland cement results in major environmental problems such as generation of carcinogens and global warming. As a result, there is a need for modern, long-lasting and environmentally feasible, and long-lasting ground renovation technology that can handle the societal infrastructure needs.

The focus of current ground improvement technology research is on biological methods that are resilient, eco-friendly, and energy-efficient. Soil-bioengineering is one such widely adopted strategy that uses vegetative root systems to stabilise soil structures against erosion. Despite its benefits for improving soil stability, growing seasons and climate variations that introduce unpredictability in the growth and proliferation of plant roots inside the soil negatively affect its performance consistency and maintenance schedules. Due to this limitation, a recent approach for soil stabilisation that are bio-mediated or bio-inspired are increasingly being used all over the world. The following sections offer an insight on biological soil improvement techniques, mechanism of bio cementation, review on literature of its application and key findings of these studies.

II. BIOLOGICAL SOIL IMPROVEMENT TECHNIQUES

The biological soil improvement techniques can be classified into bio-mediated and bio-inspired soil improvement techniques. In bio-mediated soil improvement techniques consist of using living organisms directly into the soil and the by products resulting from their biological activity can be used to alter the engineering properties of soil. In bio-inspired techniques, the stabilisation of soil does not involve the direct application of living organisms to the soil. However, different materials are used to deliver similar reactions and products into the soil.

The use of biological processes for ground improvement, particularly bio cementation, is a relatively new area and a potentially sustainable alternative strategy. The most commonly investigated bio-cementation procedures are Microbially induced calcium carbonate precipitation (MICP) and Enzyme induced calcium carbonate precipitation (EICP). MICP and EICP improve soil by facilitating Calcium carbonate precipitation via urease enzymes generated by bacteria cells or plants. MICP is a microbial metabolic activity that uses inorganic mineral precipitation (calcite/calcium carbonate; $CaCO_3$) to reinforce porous materials, ultimately improving the engineering properties of the soil. Recent applications of MICP include strengthening and stiffening soil, mending concrete fractures, producing bio-bricks from brick aggregates, and stabilizing/solidifying fly ash from municipal solid waste incineration. Microorganisms are known to proliferate quickly. Microbial activity is closely related to the differentiation, accumulation, migration, and creation of mineral deposits of numerous elements on earth. The microorganisms utilized in microbial-induced carbonate precipitation (MICP) can have a significant impact on the mechanical and engineering qualities of soil due to their quick rate of reproduction, flexible metabolism, low energy consumption, variety, abundance, and eco-friendliness. (Punnoi et al. 2021).

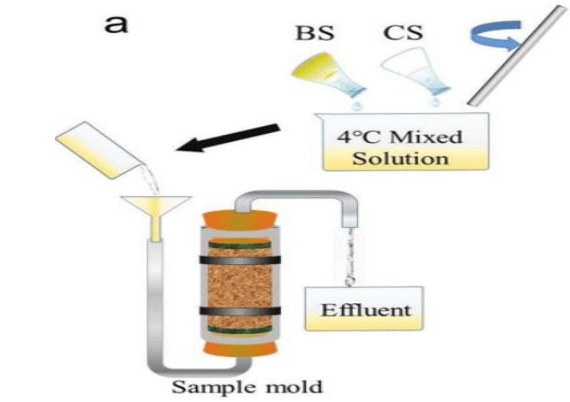

Fig. 1 Schematic representation of Microbially Induced Calcite Precipitation treatment process (Xiao et al. 2018)

EICP is an innovative bio geotechnical ground improvement technique where calcium carbonate is precipitated from an aqueous solution inside the soil pores, enhancing the bio geotechnical qualities of granular soil. Through pore filling, particle roughening, and interparticle binding, calcium carbonate precipitation enhances the strength, stiffness, and dilatancy of the soil (Almajed et al. 2018). The EICP process has the potential to be used as bio-cementation and bio-remediation solutions in many environmental, building, geotechnical, and civil engineering problems, including improving soil strength, lowering soil liquefaction potential, controlling surface erosion, lowering permeability, remediating heavy metal contaminants, and so forth (Lee et al. 2020).

$$CO(NH_2)_2 + 2H_2O \longrightarrow 2NH_4^+ + CO_3^{2-} \quad (1)$$
$$CaCl_2 \longrightarrow Ca^{2+} + 2Cl^- \quad (2)$$
$$Ca^{2+} + CO_3^{2-} \longrightarrow CaCO_3 \downarrow \text{(precipitated)} \quad (3)$$

EICP has the advantage of being effective for a larger variety of soils, including fine-grained soils, due to the smaller size of the urease enzyme crystals, which are typically 12 nm or 120 Å in size. Even though some researches have used inexpensive sources of enzyme such crude urease extract, some extraction methods may call for additional processes or chemicals and occasionally only produce modest amounts of urease enzyme. In order to cut construction costs and time, a sustainable adaption of EICP as a bio-cementation process depends on the optimization of chemical ingredients and curing time (reaction/precipitation time). In bio cemented soils, the CaCO3 that has precipitated within the soil matrix forms bridges and links between the grains of the soil particles, limiting their movement and enhancing the strength and stiffness of the soil. Application of EICP in soil stabilisation and strengthening can include liquefaction mitigation, concrete crack repair, and granular soil strengthening.

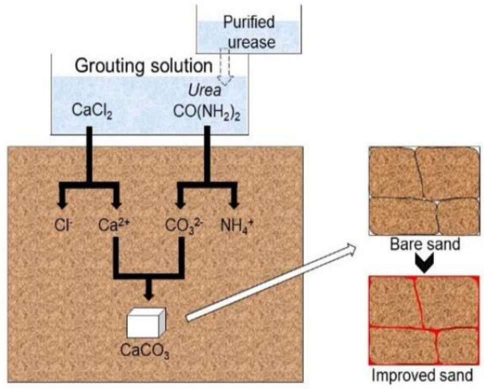

Fig. 2 Schematic of precipitation process and grouting procedure in the EICP technique
(Putra et al. 2020)

Punnoi et al. (2021) reported improvement in unconfined compressive strength (qu) of MICP treated compacted clays where Bacillus pasteurii bacterium in both vegetative cell and bacterial spore forms to induce MICP in clay specimens. The qu of treated samples after 3 days and 7 days of curing were greater than qu of untreated samples. MICP by vegetative cells and bacterial spores increased the qu values of the treated clay by 2.0 and 2.6 times, respectively. These strength increases corresponded to increases in measured calcite contents of 2.3–2.8 times. The secant Young's modulus at 50% strength (E50) also increased by 1.8 and 2.3 times respectively for MICP by vegetative cells and bacterial spores treated soils. Vegetative cells were shown to improve clay strength earlier than bacterial spores. This delay in initial performance of MICP by bacterial spores is due to its resistance against inappropriate environment, which demands some time to reactivate from spore form into active cell. The XRD patterns of treated soil showed the formation of $CaCO_3$ in the soil samples. Xiao et al. (2020) reported an improvement in unconfined compressive strength of treated soil by about 2.42 times to an unconfined compressive strength of 43.31 kPa and a reduction in clay's water content from 40% to 30.73%. A mixture of soft clay, solutions with various concentrations of nutritional salts, and Sporosarcina pasteurii bacteria was used to create soft clay specimens. A mixture of soft clay, solutions with various concentrations of nutritional salts, and Sporosarcina pasteurii bacteria was used to prepare soft clay test specimens and was subjected to 28 days curing. The direct mixing of S. pasteurii solution, nutrient salts, and soft clay considerably improves the uniformity of the spatial distribution of the bacteria and the nutrients in the soft clay and promotes the formation of calcium carbonate. The experimental study on engineering behaviour of MICP treated marine clays was evaluated through a series of one-dimensional consolidation tests, unconfined compression tests, and index property determinations. Bio augmentation and bio stimulation methods were conducted in two different types of soils, i.e., Kuttanad clay and Cochin marine clay. It was found that in the marine clay samples, it has been discovered that the biostimulation technique is ineffective; bio-augmentation is required for soil improvement. It was because, for both treatment approaches, the reduction in plasticity index appeared to be marginally superior to that for liquid limit. However, the bio stimulation strategy has only seen a slight improvement. This demonstrates unequivocally that a bio-augmentation strategy is required for the MICP method to be successful with marine clays. Reductions, in the range of 29%, were observed for liquid limit 25 days after bio-augmentation treatment. Reductions, in the range of 29%, were observed for liquid limit 25 days after bio-augmentation treatment. After MICP treatment, marine clays had their compressibility reduced by roughly 32%. At toughness limit water content, undrained shear strength of MICP treated marine clays has significantly improved (highest measured improvement is around 148%). Most of the studied specimens have a change in soil designation from CH to MH, indicating a considerable difference in soil characteristics. Even after 7 days of curing, though more slowly, the improvements in shear strength and volume change behaviour were still there (Kannan et al. 2020).

While comparing the carbonate precipitation efficiency of both EICP using soybean solution and MICP using ureolytic bacteria as a catalyst for urea hydrolysis, it was observed that because of microbial growth, the rate of MICP rises over time, but the rate of EICP falls as urease, a protein, degrades over time. However, this EICP issue can be resolved by modifying the ratio of yellow soybean to distilled water. By increasing the yellow soybean content, the rate of EICP can be adjusted to precipitate the theoretical maximum quantity of calcium carbonate in 24 hours. The microbial population can also regulate the rate of MICP, although due to the intricacy of microbial cultivation, this is more challenging than with EICP. The effectiveness of EICP's precipitation from the perspective of both precipitation capability and ease of adjusting the precipitation rate made it a great replacement for MICP. The UCS values of EICP-treated clayey sand specimens was found to be within the range of 1.58 to 2.72 for various combinations of soybean and urea– $CaCl_2$ solutions. The maximum strength was observed for 28-day cured sample treated with 140g/L urea– $CaCl_2$ solution and 3g/L soybean solution (Lee et al. 2020).

Soil improvement using plant-derived urease-induced calcium carbonate precipitation was done by Dilrukshi et al. (2018) where for the purpose of calcium carbonate precipitation, a crude extract of crushed watermelon seeds was used as the urease source alongside urea and calcium chloride. The estimated unconfined compressive strength of commercially available Mikawa sand indicated that the strength increased with respect to increase in concentration of urea- CaCl2. The highest UCS values was found for samples cured for 14 days at 0.7 M CaCl2-urea and 3.912 U/mL urease concentration. The commercially supplied urease for carbonate precipitation and usage as a low-impact approach of soil improvement could be replaced by crude urease from crushed watermelon seeds. A similar trend of results was obtained by Gao et al. (2020) where EICP was used for improving the shear strength of compacted clay liners. Compaction was conducted on soil treated with four different cementing concentrations at different moulding water contents. The treated soil samples had a UCS value greater than 200 kPa, which was considered as the minimum standard recommended for compacted clay liner, whereas the UCS value of untreated soil was less than 200 kPa. As the molarity of the urea-CaCl2 solution increased, it was observed that the shear strengths did as well. The greatest strength of 643.5 kPa was attained at 1.00 M cementation solution when the sample was prepared at -2% moulding water content in relation to OMC. The SEM image of the treated soil shows white precipitation formations. The treated soil's XRD investigation revealed that the mineral calcite was present in the soil matrix. Along with soybean and watermelon seeds, jack bean extract can also be used for bio cementation. In the study conducted by Tirkolaei et al. (2020), testing on crude and refined extracts from watermelon seeds, soybeans, jack beans, and jack bean meal in test tubes reveals that the crude jack bean extract produces the highest unit yield among these four plant sources, measured as the amount of urease per initial mass of source material. While comparing the strength of soil samples treated with crude urease extract and commercially available urease extract showed that the impurities in both the extracts play a significant role in soil strengthening, resulting in the crude extract being more effective. The efficacy of bio cementation via EICP can be influenced by the level of enzyme purity in addition to urease activity, but not always in the way that might be expected, according to test tube experiments and soil column investigations. The higher UCS results were obtained in specimens bio cemented using the jack bean crude extracts, which were much less pure than the commercially available enzymes. This result suggests that organic impurities in the bio cementation solution may actually enhance the effectiveness of EICP for bio cementation.

III. CONCLUSION

The need for adoption of biological soil improvement techniques has been increasing in the present scenario of emerging soil stabilization techniques. The focus of current ground improvement technology research is on biological methods that are resilient, eco-friendly, and energy-efficient. Geotechnical engineers and researchers are implementing microbially induced calcium carbonate precipitation (MICP) and enzyme induced calcium carbonate precipitation (EICP) all over the world. The precipitation of Calcium Carbonate (CaCO3) in the presence of the urease enzyme acts as the fundamental component of both of these processes. MICP utilises direct treatment of micro-organisms with the soil. The studies of soil stabilisation using MICP showed a considerable improvement in strength and remarkable calcite precipitation in the soil matrix. According to the results of the tube precipitation of comparison of EICP and MICP, EICP can be a great replacement for MICP due to its efficiency in precipitation as well as the ease with which the precipitation rate can be easily controlled. Since urease is created in a highly pure form for research and delicate applications, it is expensive when purchased commercially. Since urease is created in a highly purified form for research and critical applications, it is expensive when purchased commercially. The strength characteristics of diverse soils treated with urease enzyme from various sources (watermelon seeds, soybean seeds, and jack bean seeds) revealed a significant rise and effective CaCO3 precipitation. So, plant-derived urease enzyme can be a great substitute for urease enzyme that is sold commercially.

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