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Model Scale Application of Biomineralization Technique: Dynamic Cone Penetration Test and Calcite Content

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Abstract: The biomineralization technique is recently gathering consideration as a promising, environmentally sound method for bettering engineering behavior of granular media. The present research includes model scale application of the biomineralization method, generally popular as microbially induced calcite precipitation (MICP) to improve cohesionless soils. A novel bio-chemical-distribution setup was designed for the application purpose which includes a biotreatment tank of 1.35 m - length, 1.13 m - width, and 0.65 m - height. Slotted injection pipes were provided to uniformly distribute the bacterial and chemical solutions in the biotreatment tank. A 1210 kg of poorly graded sand was placed in the biotreatment tank and treated using a co-culture of *Bacillus pasteurii* and *Bacillus sphaericus* along with a chemical solution for 9 days. The biosparging concept was introduced through air pumps to maintain an aerobic environment in the soil during treatment. Untreated and biomineralized sand was tested for dynamic cone penetration test (DCPT) and calcite percent for identifying variation of the number of blows along with calcite percentage. Results showed that the dynamic cone penetration significantly increased in biomineralized soil due to the higher precipitation percent of calcite.

Keywords: *Dynamic Cone Penetration Test, Bacterial Co-culture, Biocementation, Biomineralization, Calcite Precipitation*

1 Introduction

The MICP method is effectively used as a feasible, environmentally safe ground improvement technique. The MICP technique is suitable for various applications including, hydraulic conductivity reduction, wind erosion control, strength enhancement of soil, liquefaction mitigation, heavy metal immobilization, and slope stability [1–16].

The biomineralization of calcite in between the voids of porous media strengthens the soil mass. For biomineralization, urease-producing bacteria are essential. If the bacteria is already present in the soil, then provision of nutrients solution can be sufficient to enhance the bacterial growth and uniform attachment to the soil. This is known as the biostimulation process. On the other hand, urease- producing bacteria are cultivated separately and augmented into the soil along with nutrients to the soil for attachment purposes and called as bioaugmentation process [2].The cementation solution components and their concentration are important for the amount and uniformity of calcite precipitation. Urea and calcium chloride dihydrate arethe main components of cementation solution. The biomineralized soil was found resistant to weathering actions viz freezing thawing, wetting drying, and ageing with time [17–21].

The present study focuses on the model scale application of biomineralization method. A bio-chemical-distribution setup was intended to apply MICP method in real field conditions and addressing the challenges the MICP method viz anaerobic environment at depth and non-homogenous calcite in soil media. The biomineralized soil was analysed for dynamic cone penetration resistance enhancement and calcite formation in porous media.

2 Materials and Methods

2.1 Design of Bio-Chemical-Distribution System

Figure 1 shows the novel design (schematic diagram) of bio-chem-distribution set up. The distribution system comprises a rectangular biotreatment tank which was connected with slotted injection pipes. The injection pipes were attached to the circulation tank which receives solutions from bioreactor (bacterial solution) and chemical mixer (cementation solution). Air pumps were provided united with the circulation tank for introducing biosparging concept and sparging of air in biotreatment tank during the cementation process. The drainage pipe and collection-tank was provided to drain out solutions.

2.2 Biotreatment Process

Figure 2 (a) shows image of the setup. The biotreatment tank was filled with poorly graded sand (40% relative density) over polyester filter which was covering the gravel layer (Figure 2 b, c, & d). The co-culture solution (*Bacillus pasteurii* and *Bacillus sphaericus*) of 200 L was prepared in bioreactor, augmented to the saturated sand, and allowed to hold for 24 hrs. Then 200 L of urea solution (0.50 M urea, nutrient, and buffer solutions) injected for 24 hrs.

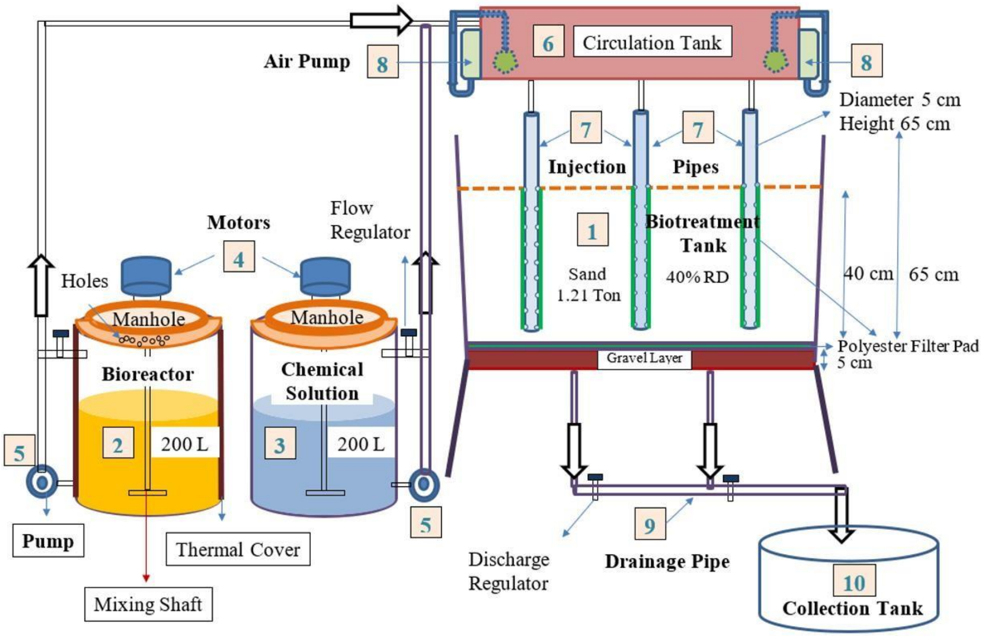

Figure 1 Novel design of system for model scale application of biocementation [9]

Further, 200 L of cementation solution (urea solution with 0.50 M $CaCl_2.2H_2O$) was injected up to 7 days in every 24 hours in biotreatment tank (Figure 2 e). Here, the concentration of urea and $CaCl_2.2H_2O$ solution were used according to optimization study in previous laboratory investigation [15]. It was interpreted that lesser concentration of cementation solution resulted in lesser amount of calcite precipitation whereas 0.50 M concentration resulted in higher and uniform precipitation. Hence, 0.50 M cementation solution concentration was used in this study. The 24 hrs of treatment cycle or injection interval was also adopted as per the results obtained from the previous laboratory investigations [1]. In this study, a new concept of biosparging was incorporated and it was implemented 10-12 hrs daily to maintain the aerobic conditions during treatment. The biomineralized sand (Figure 2 f) was tested for DCPT and calcite content, and the location of testing is shown in Figure 3 (a). The schematic arrangement of biotreatment tank and injection pipes is shown in Figure 3 (b) and (c).

Figure 2. Steps involved in biotreatment procedure [9]

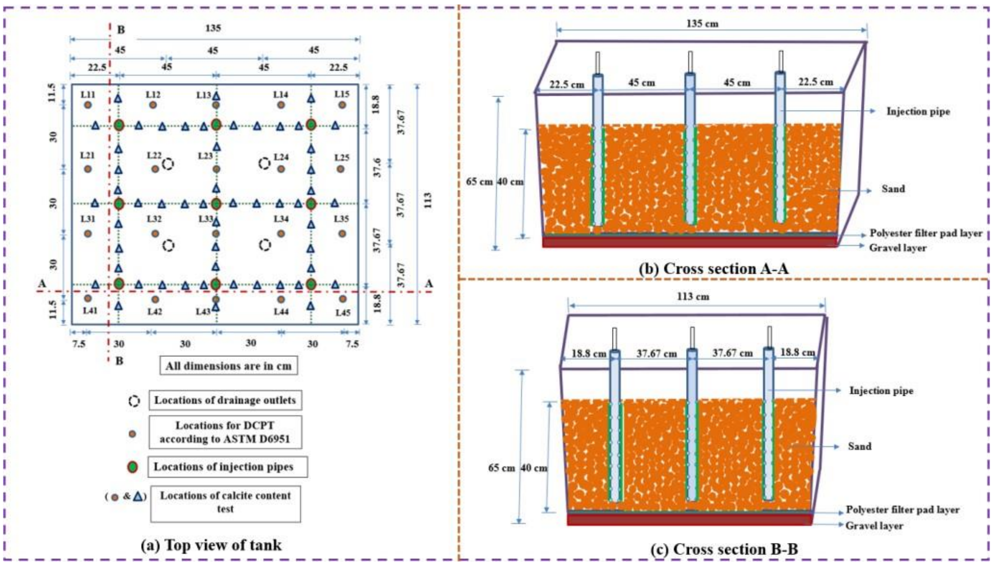

Figure 3. Testing locations and cross-section showing injection pipe arrangement in biotreatment tank filled with sand [9]

3 Results and Discussion

The sand was tested for DCPT, before and after biotreatment. The DCPT testing on untreated sand was carried out to assess the effect of boundary conditions of tank and investigate the variability in sample preparation or sand filling in tank. The sounding on biotreated sand were conducted by maintaining 30 cm distance in each test and the results were used to explore the variability of no. of blows (or penetration resistance) with calcite content precipitation at different depth.

The untreated sand was tested for DCPT at 5 different locations in tank including corners and centre locations. The number of DCPT blows was 5 at 30 cm extent in untreated sand which also confirms the uniformity in sample preparation. The biomineralized sand was tested at 20 locations for DCPT. The no. of blows ranging from 27-50 was observed along with calcite content ranging from 6.98 to 10.61% (Figure 4). A significant increase in no. of blows was observed in before and after treatment soundings. Even at the similar locations of test, there was an effective increase in cone penetration resistance. Hence, the precipitation of calcite majorly affected the cone penetration resistance.

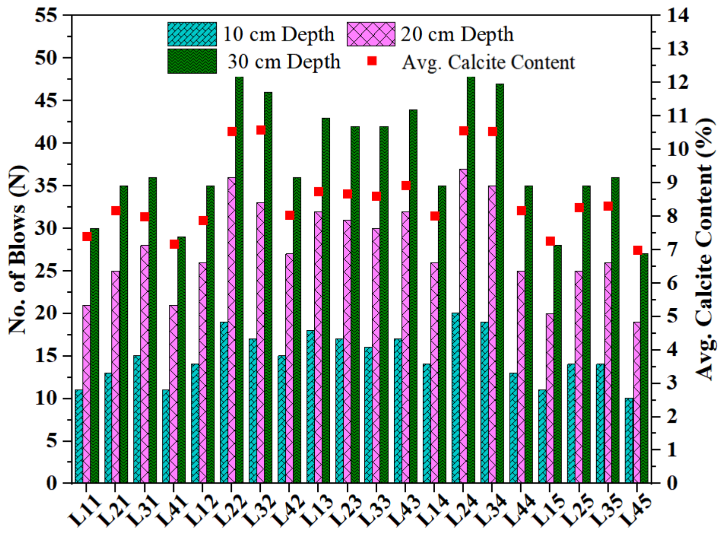

Figure 4. Variation of cone penetration resistance with calcite at different positions in Biotreatment tank

However, the no. of DCPT blows after biotreatment were observed minimum at corner locations of rectangular biotreatment tank which might be because of the distance from the injection pipes. At corner locations the calcite precipitation was also found minimum. On the other hand, at centre locations, i.e., location no. 24, 34, 22, and 32, the maximum calcite content with maximum no. of blows (nearly 46-50) were observed. The higher precipitation and penetration resistance was due to receiving the solutions from nearest four injection pipes. Thus, the distance of injection pipes also affects the variability in precipitation, as every biogeochemical reaction and precipitation creates new preferential flow paths for next precipitation mechanism. Overall, it was observed that with increment in calcite, the blows count, i.e., resistance to penetration of cone was increased and the spatial variability of calcite directly affected the cone penetration resistance.

4. Conclusion

The model scale application of MICP method was significantly affected the cone penetration resistance due to the production of calcite in voids of soil grains. The DCPT results of untreated and treated sand showed that the cone penetration resistance was significantly affected due to spatial variability of calcite content rather than the effect of boundary conditions. The methodology of treatment and setup was found efficient to produce uniform calcite precipitation, hence, the biosparging also successfully incorporated. Overall, the bioreactor can be used for bacteria suspension cultivation at real field sites along with the chemical distribution system having slotted injection pipes to achieve uniform calcite precipitation.

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