Abstract

Microbially Induced Calcite Precipitation (MICP) stands as a promising technique for soil improvement. The distinctive characteristic of the MICP technique is the in-situ occurrence of the precipitation reaction. MICP treatment involves the pre-amendment of the biological activity of the soil. A stable urea solution and a calcium source are injected afterwards. The urea hydrolysis is catalysed introducing the precursors for the calcite precipitation. Calcite binds the soil particles together and clogs the pores changing the engineering characteristics of the soil.

Although past studies show that the optimization of the MICP process is possible in controlled lab-scale experiments, the applicability of the MICP on the field-scale still requires further investigation. Some common natural conditions like high pore-water pressure, nonuniform flow fields, and soil heterogeneity have not received sufficient investigation yet. This study focuses on the assessment of MICP under these conditions in terms of the precipitation efficiency and the uniformity of precipitation profiles. This assessment was carried out employing a modified flexible-wall permeability test and a radial flow physical model test. The modified test setup allowed the continuous monitoring of the soil stiffness (represented as s-wave velocity) and hydraulic conductivity during MICP treatment. The treatment was conducted using chemical solutions of urea and $CaCl_2$ of different concentrations (0.25M-1.0M). Also, different magnitudes of hydrostatic pore pressure were applied during treatment (3-700 kPa). The feasibility of MICP for different geotechnical applications was evaluated based on the simultaneous changes in soil characteristics and the possible degrees of treatment. An up-scaled radial model was used to resemble the radial flow around an injection well, and to study MICP in heterogeneous soils. Implications for the field were based on the characteristics of the emerged precipitation profiles with regards to the hydrological condition of the specimens.

Outcomes from the modified flexible-wall permeability tests showed the hydraulic conductivity changes by MICP treatment according to two phases of behaviour. During

the first phase, no significant changes in hydraulic conductivity were noticed, while a considerable development in s-wave velocity was acquired. At a certain degree of treatment, the hydraulic conductivity started to drop dramatically while the s-wave velocity kept developing. According to these outcomes, the most appropriate application of MICP is the improvement of soil stiffness as it can be achieved with a high degree of control and uniformity. Large reductions in hydraulic conductivity are possible; however, the control of the spatial extent and magnitude of the soil's hydraulic conductivity to this level is difficult due to the difficulty of the delivery of the treatment solution. Using high-concentration treatment solutions was found to facilitate the transition to the second phase of the hydraulic conductivity behaviour. Also, the solutions of high-concentrations were associated with low precipitation efficiency. The experiment also examined the influence of the hydrostatic pore water pressure (3 kPa to 700 kPa) on MICP. MICP behaviour was not changed under the conditions that were tested. No noteworthy changes in MICP behaviour were observed.

As part of the radial model experiment, two homogeneous soil specimens were treated by low and high chemical solutions. The low concentration solution induced a high precipitation efficiency and uniformity of the precipitate profile; whereas, the use of the high concentration solution resulted in a poor uniformity and low efficiency. The precipitation was concentrated close to the injection point in the second case. The uniformity of the precipitation around the injection point was found to be controlled by both the injection flow rate, and the rate of calcium carbonate precipitation (assuming that all other conditions were fixed, including the profiles of the microbial activity).

The heterogeneous soils hindered the uniform precipitation of the calcium carbonate. It was found that higher precipitation occurred in high permeability zones compared to the low-permeability zones. However, this indicates that the formation of uniform permeability fields around the injection point is possible. The reductions in permeability are governed by the precipitate content, which is governed by the mass flux that is received by each zone.

Since the uniformity of precipitation is considered one of the major challenges in the field, the current study investigated the use of surfactants for improvement of MICP profiles. Use of different surfactants with MICP came out with a diversity of effects that include: degradation of the urea hydrolysis activity of the bacterial media, changing the delivery of the biomass, enhancing precipitation efficiency, and formation of localized filtration zones. The potential utilization of these effects for MICP treatment was proposed.