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SGC – Civil Engineering Section
LMS – Soil Mechanics Laboratory
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Pre-study and Master's Project
Fall Semester 2023
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# Enhancing energy geostructures' efficiency through Microbial Induced Carbonate Precipitation (MICP)

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## Motivation of the project

Soil thermal conductivity is one of the key parameters governing the efficiency of energy geostructures. A number of factors have varying effects on thermal conductivity from saturation to void ratio. Recent works have explored the use of microbial induced carbonate precipitation (MICP) as a means of increasing the thermal conductivity of soils and hence their efficiency for energy exploitation (Cheng et al., 2021; Martinez et al., 2019; Venuleo et al., 2016; Wang et al., 2020). There is a consensus that the application of MICP generally increases the soil thermal conductivity. The hypothesis for why this increase exists is generally attributed to the calcite crystals functioning as thermal bridges between soil particles, increasing thermal conductivity. Which raises the question of whether describing this increase using a relationship between calcite content and thermal conductivity, as done in many works, is realistic, since it is expected that a portion of the precipitated calcite is not forming active bonds. Numerical modelling frameworks exist for heat transfer processes, allowing the assessment of the energy performance of energy geostructures, and for hydro-chemical processes to simulate biocementation treatments. So far, no attempt has been found where these modelling frameworks are combined and thus a full thermo-hydro-chemical model is created to provide insight into the actual impact of a MICP treatment on the efficiency of energy geostructures.

## Keywords

Biocementation, thermal conductivity, energy geostructures, numerical modelling, laboratory experiment

## References

Cheng, L., Afur, N., Shahin, M.A., 2021. Bio-Cementation for Improving Soil Thermal Conductivity. Sustainability 13, 10238. https://doi.org/10.3390/su131810238
Martinez, A., Huang, L., Gomez, M.G., 2019. Thermal conductivity of MICP-treated sands at varying degrees of saturation. Géotechnique Letters 9, 15–21. https://doi.org/10.1680/jgele.18.00126

Venuleo, S., Laloui, L., Terzis, D., Hueckel, T., Hassan, M., 2016. Microbially induced calcite precipitation effect on soil thermal conductivity. Géotechnique Letters 6, 39–44. https://doi.org/10.1680/jgele.15.00125
Wang, Z., Zhang, N., Ding, J., Li, Q., Xu, J., 2020. Thermal conductivity of sands treated with microbially induced calcite precipitation (MICP) and model prediction. International Journal of Heat and Mass Transfer 147, 118899. https://doi.org/10.1016/j.ijheatmasstransfer.2019.118899

## Goal of the project

The main goals of the project are:
On the small-scale level (experimental work, laboratory), is to better understand the role of the calcite distribution pattern on the thermal conductivity of samples by not only looking at the total calcite content of samples, but also identifying the role of the bonding and cementation effects separately.
On the larger scale (numerical modelling), the target is to establish a modelling framework that can evaluate the effect of MICP treatment on heat transfer processes for energy geostructures.

## Tasks and work to carry out

Experimental

- Characterize the increase in thermal conductivity by measuring it at three different sample state
    - Untreated
    - Treated intact
    - Treated remolded

By obtaining these three measurements a clear explanation of the underlying mechanisms inducing the increase of thermal conductivity can be obtained. The measurements can decouple the effect of the created calcite bonds and the “free” calcite crystals on the increase in thermal conductivity.

- Link the increase in thermal conductivity to the calcite distribution in the soil through:
    - Shear wave velocity ($\Delta V_s$ ) to obtain a possible profile of calcite distribution
    - Obtaining a 3D scan of the sample to view distribution of calcite in each case

The goal would be to see how the distribution of the calcite within the sample has an effect on the thermal conductivity and possibly correlate these variations with variations on the shear wave velocity (which can then be used as a quick indicator for efficiency of treatment in field applications).

Modeling

- Develop a modelling framework linking the thermal aspects of MICP with the hydro-chemical models already developed to obtain a thermo-hydro-chemical model of MICP treated soils.
- Including thermal effects of MICP to current numerical framework.

In the first step, a numerical modelling framework is developed where the results of current biocementation simulations can be used in a second simulations step, where this

cementation profile influences the thermal conductivity of the soil domain. (2D simulation, developing the framework). This framework can be developed/validated with the experimental results and results from literature.
Use the developed modelling strategy to evaluate the influence of MICP on the efficiency of an energy pile.
Working with a 3D model and the previously developed numerical framework to evaluate the influence of the MICP injections on the efficiency of an energy pile. (3D simulation, assessing the impact).

## Deliverables

- Report

The student will have to prepare a technical report containing the introduction and motivation for the project, the description of the accomplished work and related results as well as conclusions. The technical report will have to be prepared in an electronic format and sent to the supervisor and the responsible of the project by the end of the semester.

- Final Presentation

The student will have to present his work during a presentation at the end of the semester. The day and the place of the presentation will be communicated to the student.

## Planning

- Meetings and presentations

A weekly meeting (on Friday) with the assistant is suggested to discuss the progress of the project. One meeting per month will be organized with Prof. Laloui (dates will be communicated to the student).
During the meetings with the assistant, the student will have to present (i) the progress of the work, (ii) possible questions and remarks and (iii) a summary of the next steps for the project. During these meetings, the supervisors may vary the foreseen goals of the project, if necessary.

- Electronic files

At the end of the project, the student will have to send to the supervisors a folder containing a clear classification of all the electronic files developed during the project, including those related to the reports, obtained data, presentations, poster and graphs.

## Grading

The final grade will be assigned considering the following proportions of contribution:

- Implication and initiative during the semester 20%
- Technical report 40%
- Oral presentation 40%

The evaluation will also consider the work methodology, discipline, and resourcefulness of the student.

## General rules of the project

The schedule of the project is defined by the EPFL Academic Calendar:
https://memento.epfl.ch/academic-calendar/?period=180

The student signature on the submitted report certifies that the work is original and developed by him/herself. This work is property of the EPFL and cannot be disseminated without the approval of the considered Institution.

## Contacts


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