

INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

<https://www.issmge.org/publications/online-library>

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

The paper was published in the proceedings of the 10th International Conference on Physical Modelling in Geotechnics and was edited by Moonkyung Chung, Sung-Ryul Kim, Nam-Ryong Kim, Tae-Hyuk Kwon, Heon-Joon Park, Seong-Bae Jo and Jae-Hyun Kim. The conference was held in Daejeon, South Korea from September 19th to September 23rd 2022.

MICP: Bio-grouting potential on sandy soil material

I.A. Nomleni, W.Y. Hung & M. Handayani

Department of Civil & Environmental Engineering, National Central University, Taiwan ROC

ABSTRACT: Microbacteria Induced Calcite Precipitation (MICP) is the new technology that utilizes bacteria to improve geomaterial. This method is more environmentally friendly than the cement material that may contaminate the area around the improvement area. Furthermore, this improvement method uses non-pathogenic bacteria; also, it can improve deeper layers with minimal disturbance. *Pseudomonas* sp. is one of many types of bacteria that can be used for bio-grouting that used in this study. A series of element tests were performed at the Experimental Center of Civil Engineering (ECCE) of National Central University to understand the effectiveness of MICP in improving sandy soil. The primary data used in this study were collected by three types of tests: constant head tests, direct shear tests, California bearing ratio tests, and scanning electron microscope (SEM) tests. Based on this research, it can be concluded that: (1) Microbacteria Induced Calcite Precipitation is effective in improving sandy soil, (2) The formation of calcium carbonate cement fills the spaces between sand soil particles and forms a solid bond between the particles, (3) In constant head permeability test and direct shear tests, the best way to make the highest permeability reduction in inoculation method is injecting 15% bacteria relative to total weight of soil, and (4) California bearing ratio with 10 number of hits, the treated soil can prove significant penetration stress changed. However, in CBR result with 25 and 56 number of hits the treatment soil sample got failure of the inoculation process due to the occurrence of swelling and exceeding the maximum density recommended for the application of this method.

Keywords: Microbacteria Induced Calcite Precipitation, *Pseudomonas* sp

1 INTRODUCTION

Bacteria or microbes are tiny organisms that can be observed under a microscope. Depending on the bacteria, some form a single cell or have multiple cells to form a multicellular organism. Even though bacteria are unicellular, they behave like living organisms, moving, metabolizing, reproducing, and doing several other things. Bacteria may be found anywhere and interact with each other and other organisms in either a beneficial or detrimental way. Bacteria may cause infectious diseases and food spoilage, but most bacteria contribute to the environmental sustainability of an ecosystem, specifically human welfare.

Biological cement can be made using bacteria that are non-pathogenic and environmentally friendly. In contrast to cement, soils or contaminated soils can be treated or improved without disrupting the surrounding environment. They can do this since bacteria can penetrate deeper and reproduce themselves. *Pseudomonas* species is one of many kinds of bacteria that can be used for bio grouting. Using biogrouting as technology can increase sand and rock strength and stiffness. Also, it can be used for improving slope stability, reducing foundation settlements, reducing liquefaction risks from saturated sand, reducing hydraulic conductivity, preventing soil erosion, reducing

infiltration, and strengthening concrete.

Ivanov and Chu (2008) investigated the application of microorganisms to geotechnical engineering for bioclogging and biocementation of soil in situ. According to their study, there will be three processes of bacterial inoculation in soil. A bioclogging process involves the production of a material capable of filling the pores of the soil to reduce permeability, and a biocementation process involves the production of a material that increases the shear strength of the soil. There is a process that produces biogas, namely a process in which bubbles (air) are generated through the activity of mycobacteria which can reduce the risk of potential liquefaction of sandy soils.

As a result of the other successful results, the researcher investigated the application of this method in geotechnical engineering and various other fields. So, this study was designed to find out whether biological cement works well for improving sandy soil. A constant head apparatus, scanning electron microscopy (SEM), bearing ratios test, and direct shear apparatus were used in this study.

2 TESTING MATERIALS AND APPARATUSES

2.1 Material

2.1.1 Silica sand

Silica sand was used in this experimental work. These sand grains were sub-angular and ranged from 0.42 mm to 0.074 mm in size. This sand can be classified as poorly-graded sand (SP) based on the Unified Soil Classification System (USCS). The specific gravity, sieve analysis, and direct shear tests were conducted in this study to obtain the engineering properties of silica sand. The basic properties of silica sand are summarized in Table 1.

Table 1. Basic properties of silica sand

Properties	Unit	Value
Specific gravity, G_s		2.65
D_{60}	mm	0.21
D_{30}	mm	0.17
D_{10}	mm	0.16
Coefficient of uniformity, C_u		1.34
Coefficient of curvature, C_c		0.96
Maximum dry unit weight	g/cm^3	13.83
Minimum dry unit weight	g/cm^3	12.28

2.1.2 *Pseudomonas sp.*

Selected microbacterial colonies that are anaerobic facultative with a concentration of $109 \times \text{CFU}$, so it is expected to be more flexible in the face of changing conditions. Every milliliter of liquid *Pseudomonas sp* culture contains an average of 1.5×10^8 cell microbacteria. Colonies of microbacteria were obtained from the laboratory of the Life Science Department, National Central University. In the scope of life science, *Pseudomonas sp* will produce biological glue (CaCO_3) when it reaches its mature age and gets sufficient nutrient intake. The scanning electron microscope result is shown in Figure 1.

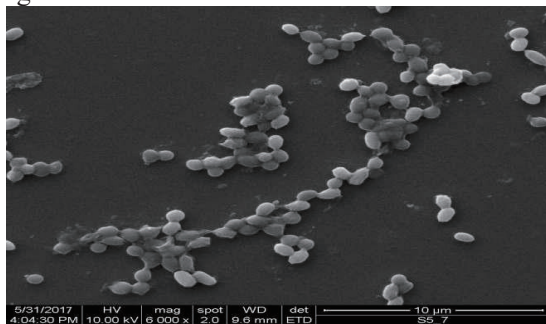


Fig. 1. Original *Pseudomonas sp.*

2.1.3 Nutrient

Nutrients are selected according to the type of bacteria. In this study, the bacterial growth nutrition used in water dissolving is LB broth powder, urea, CaCl_2 , NH_4Cl , NaHCO_3 , K_2HPO_4 , MgSO_4 , and Saccharose.

2.2 Apparatuses

In this study, the author performed constant head test to determine the hydraulic conductivity of each sample. Direct shear test to determine the shear strength of the improved soil. California bearing ratio test to estimate the bearing value of highway subbase and subgrade. Scanning Electron Microscope to produce high resolution zoomed images in order to understand the differences between original sand with and without bacteria. The apparatuses used in this study is shown in Figure 2.

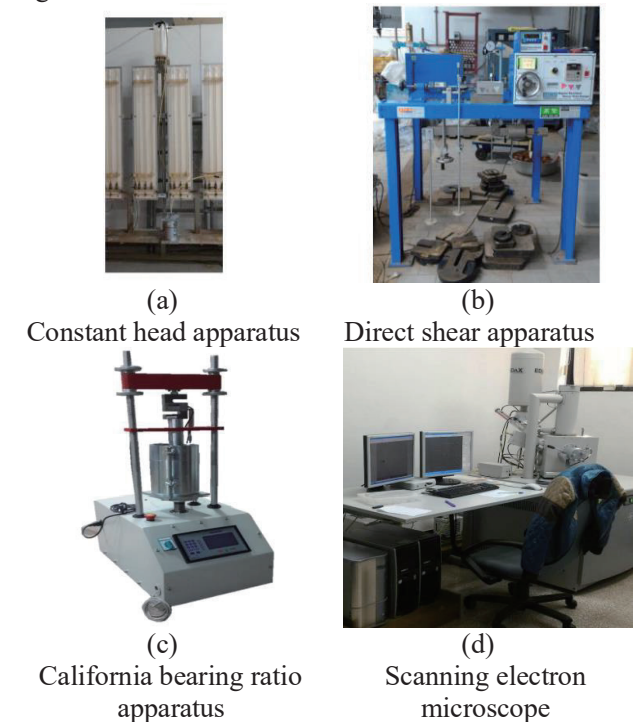


Fig. 2. Apparatuses used in this study: (a) Constant head apparatus, (b) direct shear test apparatus, (c) California bearing ratio apparatus, and (d) Scanning electron microscope

3 TESTING METHODOLOGY AND RESULTS

3.1 Testing methodology

This study performed experiments with variations of treatment days, relative density, and nutrient type. The treatment days in this experiment were divided into two different types, seven days and 28 days. This experiment also used two variations of relative density, which are 50% and 70%.

All the apparatuses and testing process for constant head, direct shear, and California bearing ratio tests were performed according to the American Society for Testing and Materials (ASTM) standard. The constant head test

is referred to ASTM D-2434-68, direct shear test is referred to ASTM D-3080-04, and California bearing ratio test is referred to ASTM D 1883-16.

3.2 Results

3.2.1 Constant head test

In Figure 3, it can be seen that the highest reduction happens in sample 28 treatment days with relative density 70% and giving nutrient once a week with the value of reduction is 74% relative to the value of original sandy soil. The second highest reduction is sample 28 days with relative density 50% and giving nutrient once a week with the value of reduction is 73% relative to the value of original sandy soil. The lowest reduction value happened in the seven treatment days' sample, with a relative density of 50%, and drowned in nutrients with the reduction value of 31% relative to the original value. From the results, bacteria inoculation method with 28 days' treatment day and give the nutrient once a week will make the highest permeability result if compared to other method with the same 28 days' treatment day. Moreover, for 7 days' treatment day, the drowned method will make highest permeability result.

This study was also conducted under different variations for bacterial content. The summary of the constant head test result for different variation of bacterial content can be seen in Figure 4. The bacterial content is divided into three percentages, which are 5%, 15%, and 25% bacterial content relative to the total weight of soil. Based on the results, it can be seen that the highest reduction happens in the sample with seven treatment days with a relative density of 50% and bacterial content of 15% with the value of reduction is 78% relative to the value of original sandy soil. If the number of injected bacteria is more but the amount of nutrients remains the same, it will cause nutrients to run out more quickly. When compared with fewer bacteria and the same amount of nutrients. Thus, the amount of calcite that is formed is more in the less injected bacteria.

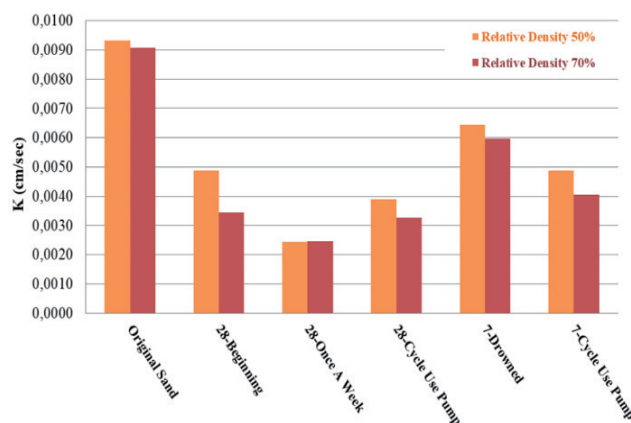


Fig. 3. Constant head test result for different variations

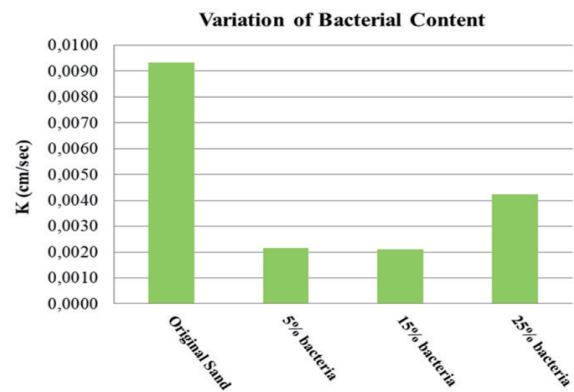


Fig. 4. Constant head test result for different variations of bacterial content

3.2.2 Direct shear test

From Table 2, it can be seen that the highest increment happens in sample 7 treatment days with a relative density of 50%, and the inoculation process is done with cycle treatment in which the value of cohesion is 6.84, and the value of friction angle is 44.46°. The second highest increment is sample 7 treatment days with a relative density of 50%, and the inoculation process is done with cycle treatment in which the cohesion value is 7.11, and the friction angle is 41.67°. Moreover, the lowest increment value happens in 7 treatment days with a relative density of 70%, and the inoculation process is done with drowned in nutrient treatment which the value of cohesion is 0.23 and the value of friction angle is 39.52°. From the result, we can know that in this experiment, the best way to make the highest shear value increase in the inoculation method is doing the bacteria inoculation method with 7 treatment days and the inoculation process done with cycle treatment.

Table 2. Summary of direct shear test

Sample	Dr=70%			Dr=50%		
	Cohesion (kPa)	Friction angle (degree)	Shear strength (kPa)	Cohesion (kPa)	Friction angle (degree)	Shear strength (kPa)
Original sand	3.82	38.22	36.61	4.28	35.94	34.47
28 - Beginning	5.03	34.02	33.13	5.07	34.27	33.44
28 - Once a week	7.28	35.95	37.47	6.05	33.53	33.64
7 - Drowned	0.23	39.52	34.58	2.54	36.87	33.77
7 - Cycle use pump	7.11	41.67	44.17	6.84	44.46	47.70

3.2.3 California bearing ratio test

From Figure 5(a), it can be seen that in the results of CBR with 10 collisions, the treated soil can prove a significant change in the penetration stress. However, in Figures 5(b) and (c), the results of CBR with a number of hits 25 and 56 treated soil samples failed in the

inoculation process due to swelling and exceeded the maximum density recommended for the application of this method.

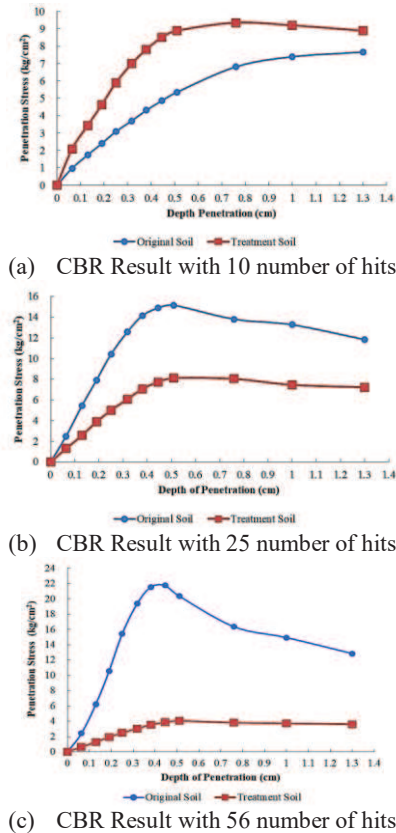


Fig. 5. California bearing ratio test result

3.2.4 Scanning Electron Microscope (SEM)

According to SEM results which can be seen in Figure 6 (a) and (b), there are differences between original sand with and without bacteria. An extracellular polysaccharide wall formed in a sample inoculated with bacteria. On the other hand, SEM results of the original sand did not show polysaccharides on the walls as shown in Figure 7 (a). However, as shown in Figure 6 (b), an extracellular polysaccharide formed attached to the sand wall, which will fill the pore space between the particles of sand and embed the particles.

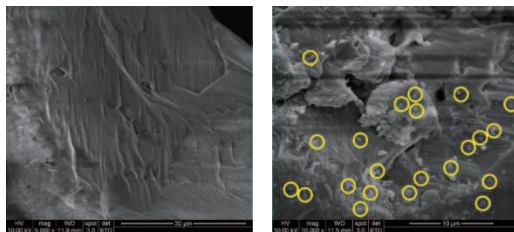


Fig. 6. Comparison of the existence of bacteria: (a) Original sand, (b) Sand inoculated with bacteria

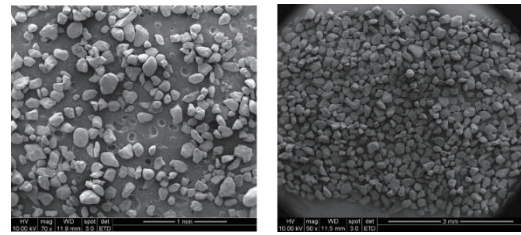


Fig. 7. Comparison of soil particle binding: (a) Original sand, (b) Sand inoculated with bacteria

4 CONCLUSIONS

Based on this research, it can be concluded that:

1. Microbacteria Induced Calcite Precipitation is effective in improving the shear strength and stiffness of sandy soil.
2. Calcium carbonate cement forms the spaces between sand soil particles and forms a solid bond between the particles. In the inoculation sand test images can be seen “biological cement” (CaCO_3) formed attached to the sand wall fill the pore space between the sand soil particles and embed the particles.
3. In the constant head permeability test, the best way to make the highest permeability reduction in the inoculation method is injecting 15% bacteria relative to the total weight of soil.
4. California bearing ratio with ten hits, the treated soil can prove significant penetration stress changed. However, in CBR result with 25 and 56 number of hits the treatment soil sample got failure of the inoculation process due to the occurrence of swelling and exceeding the maximum density recommended for the application of this method.

ACKNOWLEDGEMENTS

This study was supported by the National Center for Research in Earthquake Engineering and Geotechnical Centrifuge and Shaking Table Laboratory of Precious Instrument Utilization Center at National Central University.

REFERENCES

- Ivanov, V. and Chu, J. 2008. Applications of Microorganisms to Geotechnical Engineering for Bioclogging and Biocementation of Soil in Situ. *Rev Environ Sci Biotechnol* 7, 139–153.
- Yong, R. Nakano, M. and Pusch, R. 2012. Environmental Soil Properties and Behavior. CRC Press, Taylor & Francis Group 262-263. Florida.
- Seki, K. Miyazaki, T. and Nakano, M. 1998. Effects of Microorganisms on Hydraulic Conductivity Decrease in Infiltration. *European Journal Soil Science* 49, 231-236.
- Johnson, H.L. 1965. Artistic development in autistic children. *Child Development* 65(1): 13-16.
- Tittelboom, K.V. Belie, N.D. Muynck, W.D. and Verstraete, W. 2010. Use of Bacteria to Repair Cracks in Concrete. *Cement and Concrete Research* 40, 157-166.