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Landslide Mitigation through Biocementation

Azizul Moqsud

Abstract

Landslide and other geo-disasters are causing a great damage to people and the resources all over the world. An environment friendly countermeasure of landslide disasters is necessary. Microbially induced calcite precipitation (MICP) is a biocementation process that can improve the geotechnical properties of granular soils through the precipitation of calcium carbonate (calcite) at soil particle contacts. This MICP can be an environment friendly solution for the biocementation of soil. In this study, an evaluation of biocemented soil has been carried out through direct shear test and direct simple shear test. Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectrometry (EDS) and X-ray Computed Tomography (X-ray CT) tests were conducted to analysis the calcite precipitation inside the biotreated soil by bacteria by using Toyoura sand and silica sand no. 4. It was observed that the amount of calcite generated in silica sand was larger than Toyoura sand. The particle shape influences the result of calcite precipitation and consequent strength of the bio-cemented sand. The amount of strength which was obtained by direct shear test and direct simple shear test indicated the granular soil became bio-stabilized within 7 days of application of nutrients from the surface. However, the amount of generated calcite was not uniformed in different layers while applying the nutrients and bacterial from the surface which was revealed by X-ray CT scan test.

Keywords: Biocementation, landslide, Microbial induced calcite precipitation

1. Introduction

Landslide and slope failures are very dangerous and caused a lot of damages to the people all over the world every year. Environmentally friendly approach to improve the soil condition is necessary for the sustainable global environment. The traditional methods to protect the land against the geo-disasters such as landslide and liquefaction are mainly mechanical or chemical approach to soil and are not environment friendly. Nature has provided a significant biologically based solution to some of the challenges that vex geotechnical infrastructure systems. Recent studies on applications of bio-mediated soil improvement methods have proved the viability of the approach for effective performance and environmental sustainability. The potential outcomes of these studies have shown greater promise of exploring a wider application of the technique in geotechnical engineering. The great promise of the use of biological treatments has been demonstrated in many

applications, such as improving the shear strength and decreasing the permeability of soils [1–5] improvement in strength and durability of concrete and mortar, remediation of cracks in buildings [6–10]; improvement in engineering properties of soil and cementation of sand column [11–16]. However, the uniformity of biocementation inside the soil is not well-known yet.

The objective of this research is to look at the difference of mechanism of biocementation between the Toyoura sand and silica sand no. 4 through scanning electron microscope and x-ray CT analysis.

2. Materials and methods

2.1 Microbial preparations

There are several ideas of ground improvement method utilizing microbial metabolism, among which the calcium carbonate method has been vigorously researched in Japan and abroad recently due to the applicability to the real ground and the formation of solid matter derived from microorganisms. (*ATCC 11859*) used in this study as a source of microorganism [16, 18]. The characteristic of this microorganism is that it has the function of decomposing urea called urease enzyme. In addition, it is known that this microorganism has pressure, temperature, salt tolerance and alkali resistance, and it has a relatively strong resistance under various ground environments. The chemical reaction at that time is shown below. Cementation action between particles is caused by calcium carbonate precipitated between the soil particles, of the applied ground.

2.2 Sand used in the experiment

Two types of sands were used in the experiment to compare the effects of the size of the particles on biocementation. Toyoura sand and silica sand no. 4 were used for biocementation. The grain size analysis of those sands is shown in **Figure 1**. The particle size of silica sand is larger than Toyoura sand.

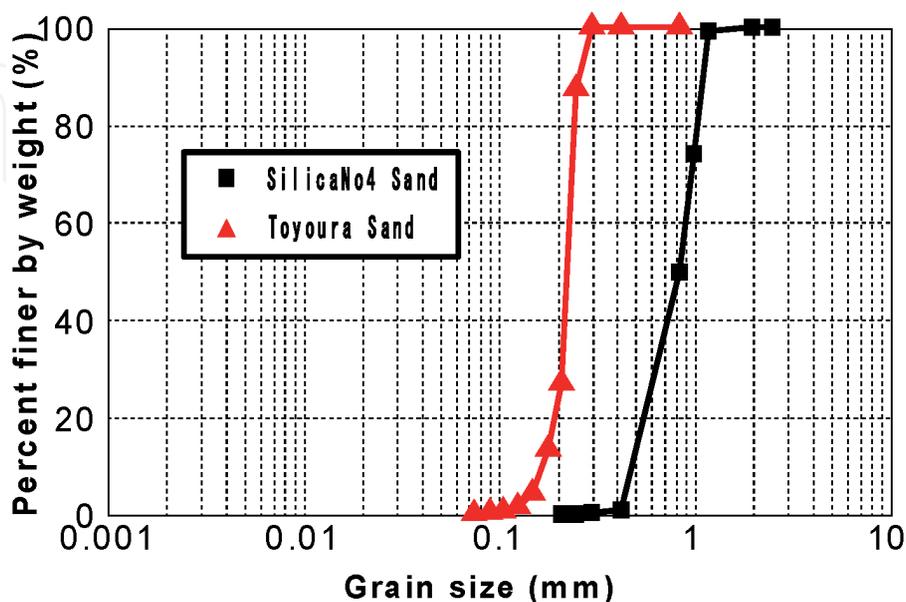


Figure 1.
Grain size analysis of Toyoura sand and silica sand used in the experiment.

2.3 Direct simple shear test

The shear strength properties measured by using direct simple shear test apparatus. The sample dimension used was 60 mm x 22.6 mm. The samples have been sheared by above mentioned apparatus under three normal loads magnitudes, namely 10, 30 and 50 kN/m². The samples under the same load magnitude have been sheared at least three times. The constant velocity of magnitude 0.2 mm/min was applied. The test is finished when the shear strain reaches 26% (**Figure 2**).

2.4 SEM and EDS analysis

The scanning electron microscope (SEM) analysis was carried out by using JSM-7600F and consequently analyzed the energy dispersive spectroscopy (EDS) to observe the surface of the bio-cemented soil particles and the mineral amount in different samples.

2.5 Micro-focus X-ray CT system

X-ray CT scan was carried out of the treated samples after 1 week of treatment for both Toyoura sand and silica sand to observe the location of the calcite generation.



Figure 2.
Direct simple shear test apparatus.

3. Results and discussion

Figure 3 illustrates that the result if the X-ray CT scan of the 1 week bio-treated sand samples. It was observed that in silica sand the amount of CaCO_3 was more than that of Toyoura sand. The shape of the sand particles has influence to generate the amount of calcite [17–22]. Another thing was observed that the amount of calcite was more in the lower portion than the upper portion of the samples. The bacteria and the nutrient was applied from the surface of the sample and this has made the influence to precipitate the calcite at the lower portion more as liquid flows through the pore spaces.

Figure 4 shows that the scanning electron microscopic view of the biotreated sand after 1 week of treatment. It was observed that the shape of the crystal is different in Toyoura and Silica sand. This type of shape of crystal might be give some influence on the strength of the biotreated sand.

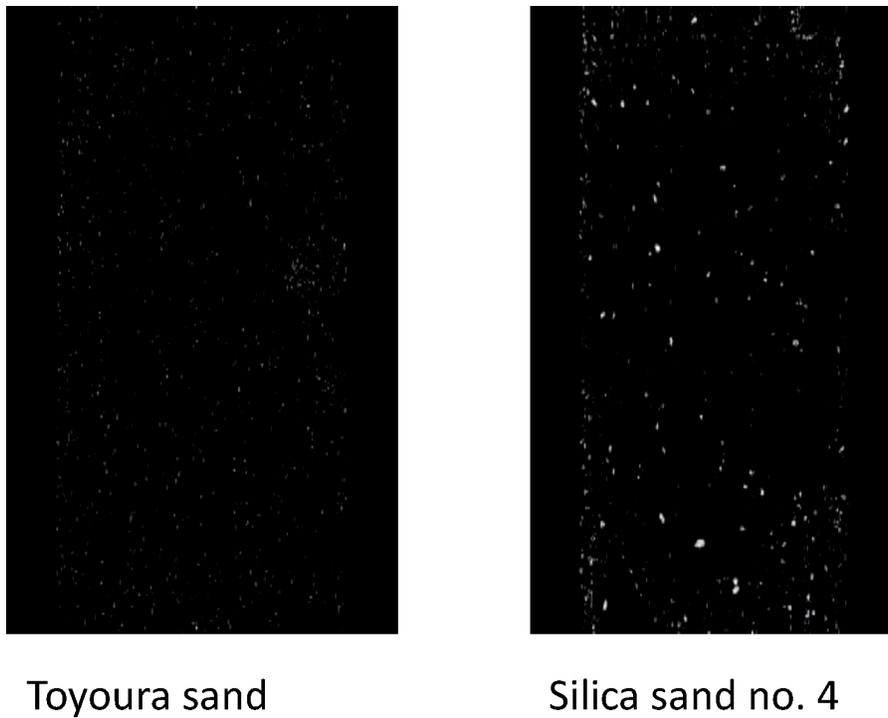


Figure 3. X-ray CT analysis (left photo Toyoura sand and right photo silica sand).

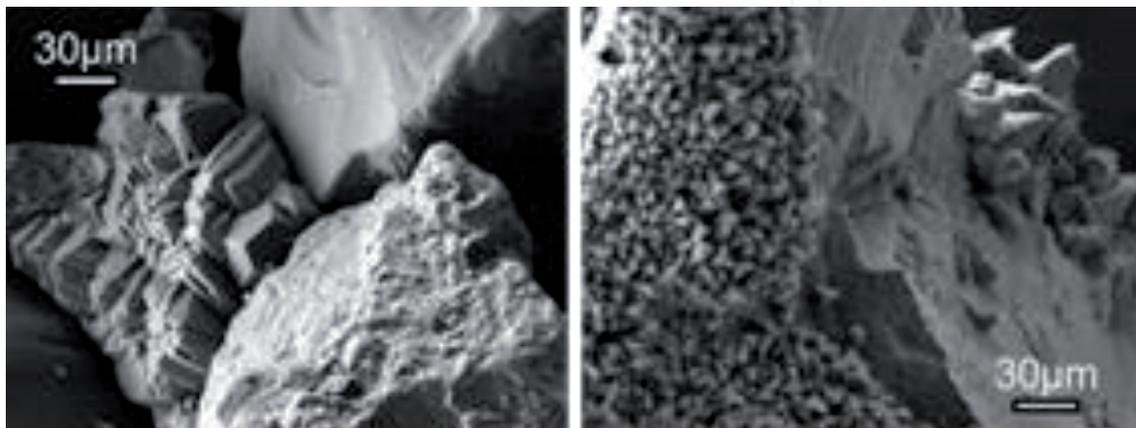


Figure 4. Scanning electron microscope (SEM) analysis of the Toyoura (left) and silica (right) sand.

Figure 5 displays the EDS analysis of the biotreated soil samples. Rhombohedral crystal (calcite) was present on the surface of the particle and Ca element was extracted from the element mapping, and the tendency that calcium carbonate is widely distributed on the surface of the particle of silica sand than Toyoura sand.

Figure 6 shows the relationship between Pca and depth of Toyoura sand and silica sand. As shown in **Figure 1**, the particle size was larger than Toyoura sand, and it was considered that calcium carbonate covered and enlarged around the particle. Rhombohedral crystal (calcite) was present on the surface of the particle and Ca element was extracted from the element mapping, and the tendency that calcium carbonate is widely distributed on the surface of the particle of silica sand than Toyoura sand. An aggregate of rhombohedral crystals with a grain diameter of rhombohedral crystal (calcite) of 10 μm to 50 μm was observed. A spherical crystal (vaterite) different from rhombohedral crystal was observed in Toyoura sand. In silica sand, existence of spherical crystal (vaterite) could not be confirmed. In addition, it was considered that the transition from vaterite to calcite was proceeding in silica sand. As the Toyoura sand and the silica sand, the shape of the particle is different they also influenced the shape of crystals.

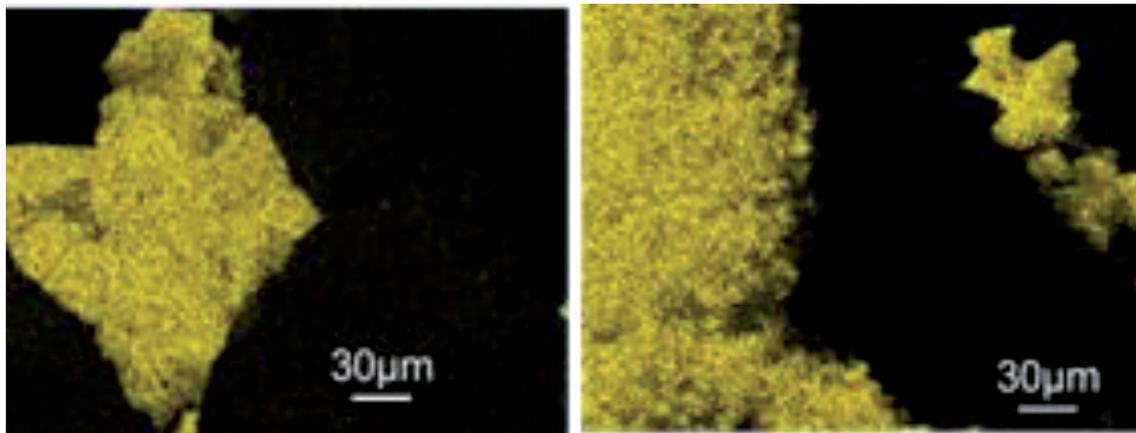


Figure 5.
EDS analysis of Toyoura (left) and silica (right) sand.

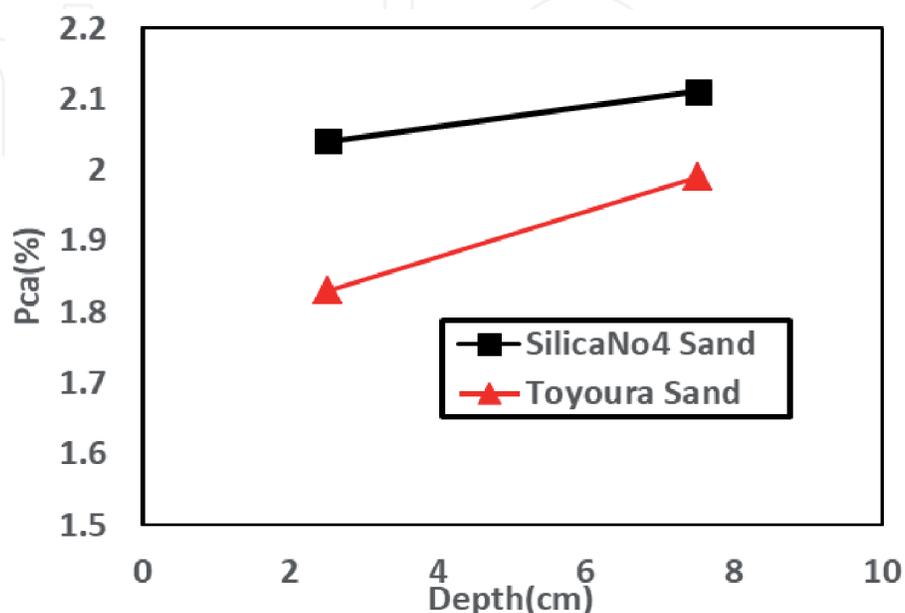


Figure 6.
Relation between calcium production and depth.

From **Figure 6** it was confirmed that silica sand Ca (calcium) element increased as compared with Toyoura sand under the same treatment condition. Since the particle size of silica is larger than Toyoura sand, calcium carbonate covers the particle surface particles, and the amount of Ca (calcium) element is higher than Toyoura sand. It was considered that it increased shear test by calcium carbonate method.

Figures 7 and 8 show the relation among the shear stress and shear strain and volumetric strain by direct simple shear test of Toyoura sand and silica sand, respectively. It shows the stress–strain relation of Toyoura sand the stress–strain relation of Toyoura sand cemented 1 Week by bio-treatment. It was observed that the shear stress value increased by 1.3 to 2.0 times in the case of no addition of microorganisms of silica sand and Toyoura sand and addition of microorganisms with 1 Week. An increase in shear stress was confirmed and from the point of comparison the shear stress of Toyoura sand was higher than the silica sand.

Figure 9 shows the relationship between the shear strength and the normal stress determined from **Figures 7 and 8**. **Table 1** shows the cohesion force

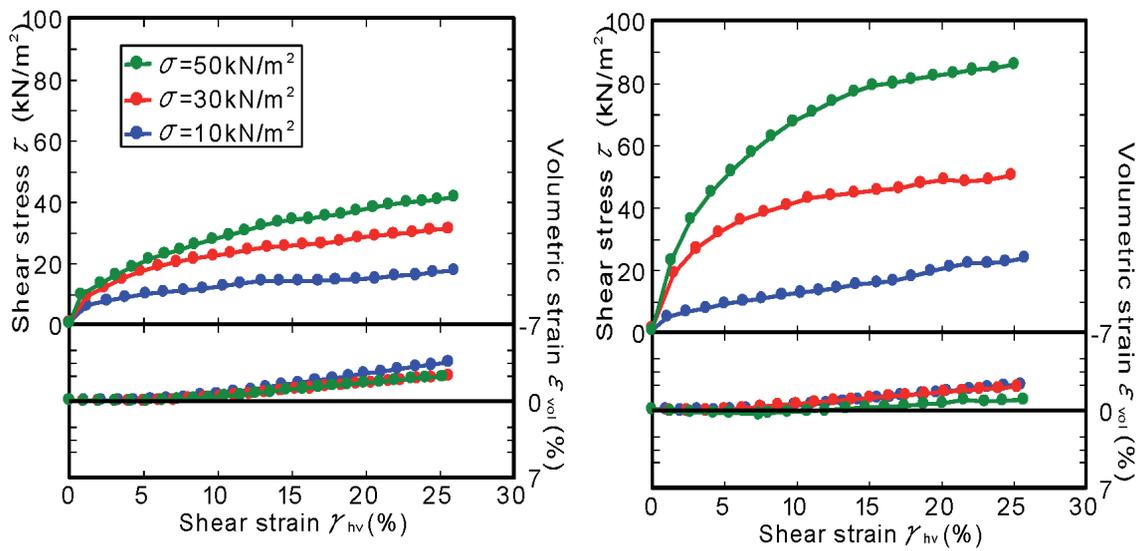


Figure 7. Relation between shear stress and shear strain and volumetric strain of Toyoura sand without (left) and after 1 week of treatment.

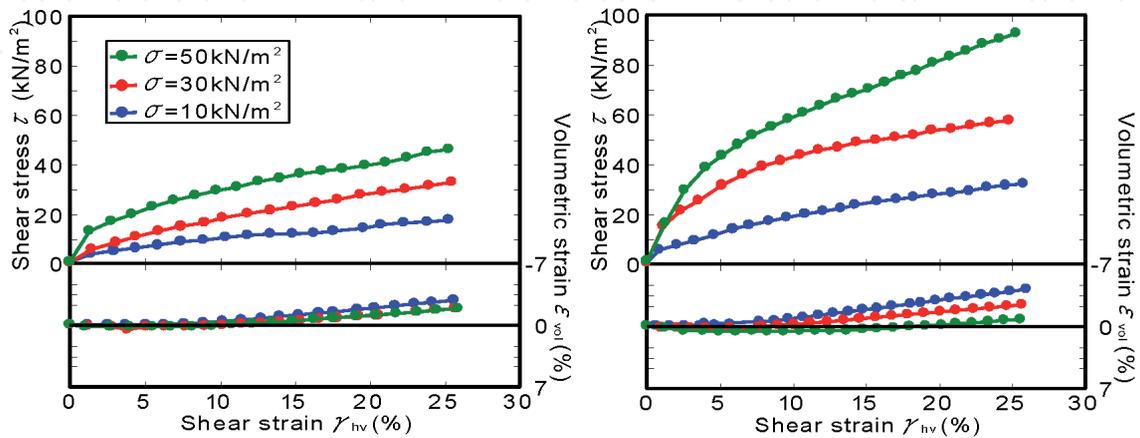


Figure 8. Relation between shear stress and shear strain and volumetric strain of silica sand without (left) and after 1 week of treatment.

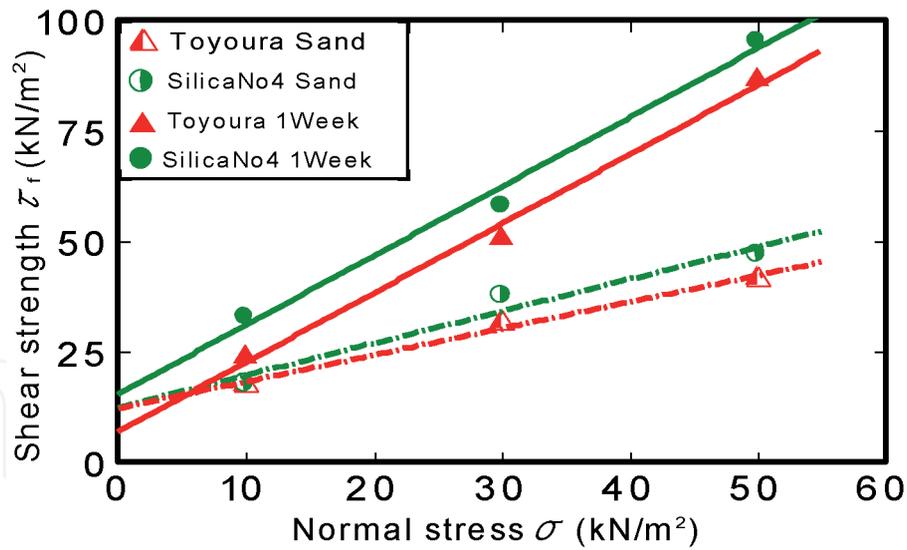


Figure 9.
 Relation between shear stress and normal stress.

	Silica No 4 Sand	Toyouira Sand	Silica No 4 1 Week	Toyouira 1 Week
ϕ (°)	35.9	30.9	57.2	57.4
c (kN/m ²)	12.38	12.19	15.07	6.56

Table 1.
 Cohesion and degree of internal friction of Toyoura and silica sand without and 1 week of treatment.

Stress	Pca (%)	
	Silica No 4 1 Week	Toyouira 1 Week
10 (kN/m ²)	2.13	1.99
30 (kN/m ²)	2.06	1.84
50 (kN/m ²)	2.37	2.04

Table 2.
 Amount of calcite generation after 1 week.

c (kN / m²) and internal friction angle ϕ (°) under each condition. From **Figure 9**, it was confirmed that the silica sand has increased cohesion force c (kN/m²) and internal friction angle ϕ (°) because precipitation of calcium carbonate on the particle surface increases the frictional force of the particle surface and the increase in density due to calcium carbonate particles. From the tendency that calcium is widely distributed, it was considered that shear stress and cohesion could be increased [23–26]. In the Toyoura sand, the shear stress increased, but the cohesion was decreased. In the Toyoura sand, precipitation of calcium carbonate on the particle surface was partially precipitated, and the calcium carbonate played the role of fine grain. After the test, Pca (%) was measured, and the calcium carbonate precipitation ratio to the sand mass was 1.8 to 2.4% The results are shown in **Table 2**. In the solidification period 1 Week by the calcium carbonate method, an average of 2% calcium carbonate precipitation could be confirmed. The slope stabilization has been also carried out by using the native bacteria and found that the soil strength has been increased significantly to protect the landslide.

4. Conclusions

It was observed through the X-ray CT and SEM-EDS analysis that the effect of particle size on bio-cementation was great. The amount of calcite generation is more in silica sand than in the Toyoura sand. In addition, it was confirmed that calcium carbonate precipitated was more in the lower part than in the upper part by infiltrating the bacteria and nutrient from the surface. It was evaluated that the precipitation distribution of calcium carbonate inside the specimen could be confirmed by X-ray CT. It was confirmed that from 10 μm to 50 μm calcite of rhombohedral crystal and vaterite of spherical crystal could be confirmed in the crystalline state of calcium carbonate in Toyoura and silica sand, respectively. It was seen the increase of 1.3 to 2.0 times of shear stress after 1 week of biotreated by using *Bacillus Pasturii*. In the cementation period of 1 week an average of 2% calcium carbonate precipitation could be confirmed.

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References

- [1] Gowthaman, S., Mitsuyama, S., Nakashima, K., Komatsu, M., Kawasaki, S. Biogeotechnical approach for slope soil stabilization using locally isolated bacteria and inexpensive low-grade chemicals: A feasibility study on Hokkaido expressway soil, Japan. *Soils and Foundations*, Vol. 59, 2019, pp. 484-499.
- [2] DeJong, J.T., Mortensen, B.M., Martinez, B.C., Nelson, D.C., Biomediated soil improvement. *Ecol. Eng.* Vol. 36, 2010, pp. 197-210.
- [3] Moqsud, M.A., Soga, K., Hyodo, M., Nakata, Y. Evaluation of bio-cemented sand for landslide disaster prevention. *International symposium on bio geotechnology*. September 12-13, Atlanta, USA. 2018.
- [4] Bao, R., Li, J., Chen, L. Effect of microbial induced calcite precipitation on surface erosion and scour of granular soils proof of concept. *Journal of transportation research board*, Vol. 2657, 2017, pp. 10-18.
- [5] Stocks-Fisher, S., Galinat, J. K., Bang, S. S. Microbiological precipitation of CaCO₃. *Soil Biology and Biochemistry* Vol. 31(11), 199, pp. 1563-1571.
- [6] DeJong, J., Fritzsche, M. & Nüsslein, K. Microbial induced cementation to control sand response to undrained shear. *Journal of Geotechnical and Geoenvironmental Engineering* Vol.132 (11), 2006, pp. 1381-1392.
- [7] Gomez, M.G., Anderson, C.M., Graddy, C.M.R., DeJong, J.T., Nelson, D.C., Ginn, T.R. Large scale comparison of bioaugmentation and biostimulation approaches for biocementation of sands. *Journal of geotechnical and geoenvironmental engineering*, Vol.143, 2017, 4016124.
- [8] Jiang, N.J., Soga, K. The applicability of microbially induced calcite precipitation for internal erosion control in gravel-sand mixtures. *Geotechnique*, Vol. 67, 2017, pp. 42-55.
- [9] Moqsud, M.A. Bioremediation of polluted soil due to tsunami by using recycled waste glass *Scientific reports*. 11 (14272), 2021
- [10] Imran, M.A., Kimura, S., Nakashima, K., Evelpidou, N., Kawasaki, S. Feasibility study of native ureolytic bacteria for biocementation towards coastal erosion protection by MICP method. *Applied science*, Vol. 9, 2019, pp. 4462-4475.
- [11] Jonkers, H.M. Toward bio-based geo and civil engineering for a sustainable society. *Procedia Engineering*. Vol.171, 2017, pp. 168-175.
- [12] Gomez, M.G., Graddy, C., DeJong, J. and Nelson, D. Biogeochemical changes during bio-cementation mediated by stimulated and augmented Ureolytic Microorganisms. *Scientific Reports*. Vol. 9, 2019, 11517.
- [13] Cui, M.J., Zheng, J.J., Zhang, R.J., Lai, H.J., Zhang, J. Influence of cementation level on the strength behavior of bio-cemented sand. *Acta Geotech.* Vol. 12, 2017, pp. 971-986.
- [14] Montoya, B.M., De Jong, J.T. Stress-strain behavior of sands cemented by microbially induced calcite precipitation. *J. Geotech. Geoenvironmental Eng.* Vol. 141.2015
- [15] Cheng, L., Cord-Ruwisch, R., Shahin, M.A. Cementation of sand soil by microbially induced calcite precipitation at various degrees of saturation. *Can. Geotech. J.* Vol. 50, 2013, pp. 81-90.
- [16] Bareither, C.A., Edil, T.B., Benson, C.H., Mickelson, D.M. Geological and physical factors affecting the friction

angle of compacted sands. *J. Geotech. Geoenvironmental Eng.* Vol. 134, 2008, pp. 1476– 1489.

[17] Canakci, H., Hamed, M., Celik, F., Sidik, W., Eviz, F. Friction characteristics of organic soil with construction materials. *Soils Found.* Vol. 56, 2016, pp. 965-972.

[18] DeJong, J.T., Fritzsche, M.B., Nußlein, K. Microbially induced cementation to control sand response to undrained shear. *J. Geotech. Geoenvironmental Eng.* Vol. 132, 2006, pp. 1381-1392.

[19] DeJong, J.T., Mortensen, B.M., Martinez, B.C., Nelson, D.C. Biomediated soil improvement. *Ecol. Eng.* 36, 2010, pp. 197-210.

[20] Dhami, N.K., Reddy, M.S., Mukherjee, A. Significant indicators for biomineralization in sand of varying grain sizes. *Constr. Build. Mater.* 104, 2016, pp. 198-207.

[21] Farukh, M.A., Yamada, T.J. Synoptic climatology of winter daily temperature extremes in Sapporo, northern Japan. *Int. J. Climatol.* 38, 2018, pp. 2230-2238.

[22] Feng, K., Montoya, B.M.,. Quantifying level of microbial-induced cementation for cyclically loaded sand. *J. Geotech. Geoenvironmental Eng.* Vol. 143, 2017, 06017005.

[23] Feng, K., Montoya, B.M. Influence of confinement and cementation level on the behavior of microbial-induced calcite precipitated sands under monotonic drained loading. *J. Geotech. Geoenvironmental Eng.* Vol. 142, 2016, 04015057.

[24] Soon, N.W., Lee, L.M., Khun, T.C., Ling, H.S., Factors affecting improvement in engineering properties of residual soil through microbial-induced calcite precipitation. *J. Geotech. Geoenvironmental Eng.* Vol. 140, 2014, 04014006.

[25] Van Paassen, L.A., Ghose, R., van der Linden, T.J.M., van der Star, W.R. L., van Loosdrecht, M. C. M. Quantifying biomediated ground improvement by ureolysis: large-scale biogrout experiment. *J. Geotech. Geoenvironmental Eng.* 136, 2010, 1721-1728.

[26] Moqsud, M.A. Slope Soil stabilization through biocementation by native bacteria in chugoku region, Japan. *International Journal of Geomate.* Vol 21 (81): 36-42.