RESEARCH ARTICLE

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Clayey Soil Stabilization by the Inclusion of Banana Fiber and Microorganisms in the MICP Technique

Soundaryan Gopi [a,*]

[a] Department of Civil Engineering, Excel Polytechnic College, Komarapalayam-637303, Tamil Nadu, India

* Corresponding Author: Soundaryangobi@gmail.com

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Abstract: MICP is a process to produce bio cementation by using a hydrated lime and it is an inorganic compound of $Ca(OH)_2$ is a white crystal or white powder called as a quicklime. And which the calcium ions in the lime are present in the research. In this research the *bacillus magateriumand Bacillusmycoides* bacteria with lime upon the two separate ways by using the bacteria in the different molarities of 0.25, 0.75, 0.75, 1.Bananafibre is mixed with the clayey soil and the silt clay soil to maximize the strength to reduce the moisture content or to make it as dry moisture content. Puzzolona may mix with lime powder to maximize the strength. The experimental is to be maintained in the research of bacteria as (*Bacillus magaterium*) and (*Bacillus mycoides*), it is dissolving phosphorous and potassium, promoting growth and control the plant diseases. This may do mainly in the untreated soil and mainly done in the clayey soil, silt clay and fine loamed soil to find the strength according to the different molaties. The engineering behaviour is treated sand by using the bacteria in the unconfined test, CBR test, Specific gravity, PH test. The permeability of sand is minimized in the range of 6.3xE-3 to 3.2xE-5cm/s. It may use in the ground improvement process and other construction process to maximize the compression strength by testing in the unconfined compressive strength. The experimental findings with the help of using the scanning electron microscopy (SEM) and energy disperse x ray analysis (EDX). The research will finally show the maximum compression strength of molarity in the MICP process. The lime may attain the more compressive strength by using the banana fibre can be effectively adopted to enhance the engineering characteristics of sand.

Keywords: Quicklime Powder, Bacillus Magaterium, Bacillus mycoides, Bio cementation, Banana fibre, Molarity, Microscopic analysis.

1. Introduction

In the construction area, the common problems of soil will be the durability and the stability, and it is due its nature. The test may mostly do in the cohesive soils and mostly done in the untreated such as a clayey soil, silt clay and the fine loamed soils by suing the banana fibre to reduce the moisture content. The nature of the soil will be low compressible, low durability, low stability. This test mainly done for ground improvement process. The soil can stabilize mechanically with stabilization geosynthetic and achieved the confinement of particle movement to improve the entire soil layer. [1] The calcium and potassium may present in the banana fibre and the previous research implies that the chemical composition may use to improve the soil strength. A researcher proves that the rubber coated banana fibre may give the more compression strength when compared to the other agricultural wastes. The agricultural wastes such as rice husk fly ash and etc may also has the capability to find compression strength for the clayey soils. According to the research the following equation will be,

Urea (1) $(CO(NH_2)2) + 2H_2O \rightarrow$ ammonium $(2NH4+)$ + Bicarbonates (CO_3^{2-}) (I)

External calcium source $(Ca2+) + CO_3^{2} \rightarrow$ calcium carbonate $(CaCO_3) \downarrow$ (II)

So, the clayey or the loamed soil may use for the agricultural purposes and the other purposes. This may be suitable for the ground improvement process. So, soil stabilization by using the bacteria may give the more shear strength and the compression strength [2] may test the eggshell and the calcium chloride in the two ways such as hand and the grouting process. In the other way grape seed may grows in the rich loamed soils. It is one of the agricultural wastes. By mixing with the loamed clayey soil by using the MICP in bio cementation process may give the more shear strength and the compression strength. The LB broth is high rich nutrient process similar to that of the nutrient broth and there are several methods are lb preparation, autoclaving and urea preparation, mixing bacteria in ml and mixing urea by using the pipette. [3] By using the LB broth it is more preferable than the other broth and it is similar to that of the process and it is nutrient rich process. MICP process is environmentally friendly, so that the bio cementation technique is to be recommended.

Around the nearly 3.6 million tons of cement may produce and approximately 6% of manmade greenhouses may be produced. This may produce mainly due to the carbon dioxide makes the ecosystem and environment is to be polluted. The loose soil may have the poor strength and the huge settlement characteristics. Because of the poor strength the loose soil cannot be used for the construction purposes. The clayey soil is preferable because of less moisture content, and it has more strength when compared to the loose soil Generally calcium carbonate crystals coat the soil particles to fill out the pores partially [4] may simplify the bacterial cultivation medium adopting an inexpensive food grade yeast medium and found to be effective in the calcium carbonate. And only limited number of studies in the literature have reported due to use of the alternative calcium sources for the calcium chloride. The various number of bacteria

in the aerobic process such as Salmonella typhi, B substilis, L fusiformis, B plasteuri, B magaterium and Proteus vulgaris, B. sphaericus are the various types of bacteria may test in the MICP process may be respectively. [5]

2. Materials and Test Methods

2.1 Sand

Silt clay may use in the MICP process and the sample of the soil may take from the various places to testing and its particle size nearly ranges from 0.02 and 0.06 mm. it's mainly non-plastic and low plasticity material because of the fine particles and clay content of this silt may be around more than 50%.calyey soil naturally reduces the moisture content and it is an high bonded material by using the mixture of the banana fibre gives more shear and the compressive strength. The index property of sand had arrived by adopting Indian standard testing procedures. The index property test data of sand of specific gravity ranges from the 2.65 to 2.85, natural moisture content 32% as 0.32, PH value of silt clay ranges from 5.5 to 8.5 either side of neutral). These index properties of sand concluded that sand was a poorly graded type per the IS classification system.

2.2 Banana Fibre

The banana fibre extracts mainly from banana sheath by mechanical method with the combined treatment with NaOH 1, 2, 3, 4, 5%. NaOH is used to remove the other impurities. In the stem of banana tree undergoes de-centrifugation process using knife and is kept for drying in the oven at 100 to 110°C for almost three weeks. The dried decorified banana trees are cut into various and shorter lengths and proceed to the grinding process until the fibre passed through 63μm of the sieve size. The properties of banana fibre are shown in Table 1.

Table 1. Properties of banana fibre

Sl no	Property	Range
1	Cellulose (%)	62.5 – 66.98
2	Hemicellulose (%)	6 – 19
3	Lignin (%)	5.0 – 10.0
4	Moisture (%)	10 - 11
5	Density(g/cm3)	1 – 1.5
6	Elongation at break (%)	4.7 – 6.6
7	Youngs modulus (GPa)	18.5 – 20.1
8	Lumen size(mm)	5
9	Microfibrillar angle(deg)	11

Banana fibre composites 10% 20%, 30% weight according to the clayey sample. shown that 20% weight of banana fibre may give good results. So, 10 to 20% of weight can be used for tests to improve they strength of the clayey soil. NaOH treatment is the best method for the banana fibre. Figure 1 shows that the percentage wise NaOH solution mixed with banana fibre.

1% Naoh 2%Naoh 3% Naoh 4% Naoh

Figure 1. After mixing % of Naoh solution in the banana fibre

2.3 Bacterial Precipitation

In the former research acetobacter is used in the process mainly to convert the liquid from legan may converted into the cellulose and it may mainly use for the mixture of drinks and packing foods names as Bacterial cellulose fibre composite produced by the fibres extracted from the banana peel waste.

Now in this research *B mycoides* and *B magaterium* used in the MICP process. The Researcher Gowthaman et al (2019a) is concluded the native bacteria gave the environmental benefits through the elimination of nonbacterial natural on the soil ecosystems. In the MICP process produces less the treatment implementation costs and detrimental environmental impacts based on the energy and the material usage. By sing this bio cementation process by using this bacterium may gain the strength for the ground improvement and the other construction purpose. It may demonstrate that the native bacteria perform urea hydrolysis at slower rates than the exogeneous in their native strain. The native bacteria as well adopted bacteria that represent and are difficult to eliminate. Both the properties to the bacteria are shown the table 2. [6]

2.4 Bacillus Megaterium VS Bacillus Mycoides:

The new name of the bacteria will be Priestiamegaterium. It is a gram positive, endospore forming, rod shaped bacteria and it considered as an aerobic it is mostly found in the soil considered as a saprophyte. It is one largest bacterium is about 100 times as large as E. It may use to dissolve phosphorous and potassium, potassium growth and used to controlling the

plant diseases. The bacteria have a wide temperature range (3°C to 45°C) makes it an ideal industrial organism. It grows and extract from the soil, seawater, sediments, rice paddies, dried food, honey and milk may be respectively.

It is a rod-shaped endospore forming aerobic or facultative anaerobic, gram-positive bacteria in some species cultures may have a gram negative with age. Bacteria nearly grow in the Petri plates it may present in a wide variety of environments especially soil. They can survive with or without oxygen and grows at the temperature ranging from 10°C to 15°C to 35°C to 45°C. The roles of this bacteria may be reinforcing polysynthetic efficiency, antioxidant Défense, express of stress responsive genes and ameliorates the effects of salinity stress in the maize may be respectively [7].

Table 2. Basic properties of B. Megaterium and B. Mycoides

Sl.no	Bacteria Property	Bacillus Megaterium	Bacillus mycoides
1	ATCC number	14581	6462
2	Urease nature	Positive	Positive
3	Gram staining	Positive	Positive
4	Shape of bacteria	Rod	Rod
5	Growth medium	Luria broth	Luria broth
6	Length (micrometre)	4µm	3 to 5
7	Width (micrometre)	1.5µm	1 to 1.2
8	Cell concentration(cfu/ml)	10x10^5to 50x10^5	1x10^7
9	Optimum temperature(°C)	30 °C	30 to 37°C
10	Optimum PH	6.0	5.0

3. Cementing materials

The cementing chemicals play a vital role to produce calcium precipitation the MICP. The various ingredients are shown in the table 3. In this lime may use in four different molarities such as 0.25, 0.5, 0.75, 1 are respectively. By using lime may give an additional strength to clay or cement .it may be tested in hand mixing or in the grouting process may be respectively [8].

$$\text{Molarity} = \frac{\text{(Molecular weight of lime) x (needed molarity of 0.25, 0.5, 0.75, 1) x 100}}{1000}$$

Lime may be mixed with the white vinegar in the ratio of 1:8 weight and then this mixer is kept in the mechanical shaker for 7 days.

Table 3. Chemical composition of Quicklime

Sl no	Item	Percentage
1	Cao	94.18
2	MgO	2.29
3	SiO_2	0.89

4	SO_3	2.64
5	Al_2O_3	0
6	Fe_2O_3	0
7	Residue (no. 100 mesh)	3.12

The size of the quick lime is less than that the 0.4 mm to 2mm may be respectively. The components present in the lime are shown in table 2. And the ph. and alkalinity of the lime will be nearly 12.5 and basic. While doing the tests ph. range may vary according to the lime sample may be respectively. [9]

4. Lime VS Egg Shell

In the previous research shows eggshell while mixing with the soil clay has more shear and the compression strength according to the different molarities.PH value of the eggshell may vary 4.8 and acidic and the ph. of the lime may vary 12.5 and basic. Egg shells were mixing with the white vinegar as well as the same process such as a quick lime were also mixed with the white vinegar. Lime and eggshell both have a calcium, so that eggshell is a source of calcium carbonate ($CaCO_3$) that when properly calcinated and be transformed into quicklime (Cao) and later into the Hydrated lime ($CaOH_2$). From this lime and shell may nearly shows the same results and it helps to the ground improvement process and such lime and eggshell may use for clay soils and cement materials may be respectively [10].

4.1 Bacterial culture preparation

The Bacillus mycoides and Bacillus megaterium were cultured with Luria broth powder at 130 rpm and incubation temperature of nearly 35°C to 40°C. The different chemical composition of lipuria broth powder (L. B) are listed in the table 4.

Table 4. Ingredients of cementing chemicals

Slno	Constituent	Cementing material	Sterilization
1	Urea	0.25 molarity	Syringe filter
2	Calcium chloride	0.25,0.5,0.75 and 1.0 molarity	Autoclave
3	Lime (pure lime)	0.25,0.5,0.75 and 1.0 molarity	Autoclave
4	Luria broth powder	3 to 5 g	Autoclave
5	Ammonium chloride	1.86 molarity	Autoclave
6	Sodium bicarbonate	2 to 2.5 g	Autoclave + dry
7	PH	7.5	-

The LB powders of 13g were added with 1L of deionized water and placed for autoclave for 10 to 15 min. Then the mixer was incubated at 37°C for 1day. After 1 day, the mixers were added with1 to 2% of inoculums are placed in an orbital shaker for 1 day at 120 rpm. Lastly the

bacterial culture was harvested and preserved at a temperature of 4 °C before use [11]. In this process the both the bacteria were injected with the nutrient broth or the Luria broth and then the urea should be added and need to be centrifuged. The urea is prepared by using a pipette of 150 micron.

4.2 Urease Test for Bacillus Megaterium and Bacillus Mycoides

The bacteria are utilized in this research subjected to the urease test to realize the function of bacterium in hydrolysing urea and produce the ammonium and the carbon dioxide. Luria broth is made of peptone from casein, yeast extract, sodium chloride and agar and autoclave the mixture for 25min at 120°C. The test consists of urea 20g/l, sodium chloride 10g/l, peptone 10g/l, yeast extract 5g/l, potassium dihydrogen phosphate 2g/l and agar 15g/l and phenol of 0.012 g/l and 1 L of distilled water is to be added. In the UAB media was first sterilized and the leftover components of UAB medium are autoclaves. UAB slants are inoculated with both the bacteria such as Bacillus mycoides and Bacillus megaterium fresh culture, and the components were placed at b30°C for inoculation. Then the urea hydrolysed, ammonia accumulates in the medium and takes it as alkaline [12]. This hike in the Ph indicator the colour to same colour as nutrient broth as yellow colour changes to the deep pink and the ph. will maintains within the range of 6.8 to 7.2 and it is a positive test for the urea hydrolysis .Negative samples may shows yellow in colour and the positive samples are deep pink in colour as well as nutrient broth may be respectively. Glucose will not use in this process because it reduces the PH.

Table 5. Chemical composition of Luria broth powder

Sl no	Chemical composition	Quantity
1	Peptone	10g/l
2	Yeast extract	5g/l
3	Sodium chloride	10g/l
4	Urea solution	10ml
4	Agar	12.5g

Note: For 100 ml of distilled water 1g of peptone, yeast extract 0.5g, sodium chloride 1g, urea solution 1ml and agar 1.25g will be added and for 1000ml as 1L of distilled water 10g of peptone, 5g yeast extract, 10g of sodium chloride, 10ml of urea solution and 12.5 g of agar will be added. This is the way of procedure to mix these ingredients to prepare the Luria broth miller agar.

5. Soil Sample Preparation for UCS

In this preparation two types of process are done, hand and grouting process. A schematic of the experimental set up is shown in Figure 2. In the grouting process the injection technique was prepared in unplastized polyvinyl chloride (UPVC) with an inside diameter of

40mm and a height of 80mm. All the samples are prepared as per procedure. A 15mm thick drainage layer made of gravel and a synthetic filter were placed top and bottom of the tube. Then out of height 80mm nearly 50mm full of covered with the clayey soil and the remaining 30mm, 15mm at the top and then the 15 mm in bottom surface is to be covered. Four (UPVC) pipes are used for the four different molarities 0.25, 0.5, 0.75.1.0 respectively. In that top of the pipe four tubes are connected on the surface for injecting bacteria and the cementing media may be respectively.

The pipe is located vertically as a column surface for injecting bacteria and the cementing media, and the pipes are attached front side of the wooden box for the mechanical support to pour the media may be respectively. In that silt clayey sample, banana fibre is to be mixed for 10 to 15% of weight from the soil may be respectively. [13]

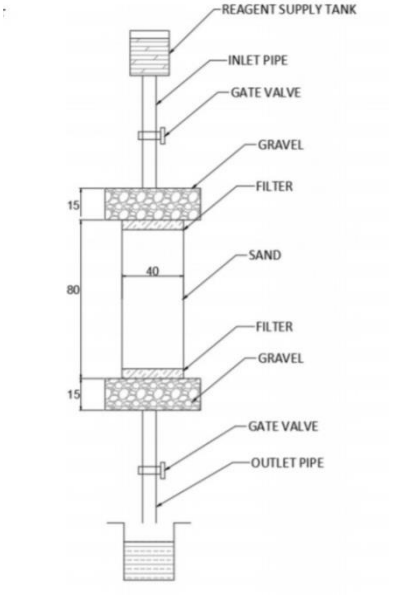

Figure 2. Experimental setup for UCS line sketch view

5.1 Test for 1, 3 And 7 Days as Per Sample

After the injection process, we can one day for first test, after that removal of the pipe and take the mould and kept in the oven for 70 to 100ºC and may test in the unconfined compression machine 1.25 strain and note the reading and then the same test repeated for 3 day and again repeat the process and then for 7 days and compare the strength of four different molarities is to be tested. And note the results of the tests may be respectively.

5.2 Tests for soil sample

5.2.1 Permeability Test

The permeability test of coarse-grained soils is determined in the laboratory with the help of the constant head load. The laboratory permeability tests are conducted as per Indian Standard IS-2720 Part-XVII. The samples were prepared in a cylindrical mould having an internal diameter of 100mm and a height of 127.3mm. The sand samples were oven-dried at a temperature of 105°C for 30min to remove the contaminated microorganisms (contaminated microorganisms affect the calcium carbonate precipitation) from the sand samples. Afterwards, the bacterial solution was injected into the soil samples and left in the solution of 12h. After 12h, the soil sample was treated with a cementing medium and left in the solution 0f 12h. The procedure was repeated for 3 days. Then the treated samples were cured for 7days and tested using a permeability apparatus. [14]

5.2.2 Unconfined Compressive Test

The unconfined compression strength tests of soil samples carried out by IS 2720-Part X .The UCS samples had 38mm diameter and 76mm of length with a diameter to length ratio of 2.0.In this test, after the settling of bacteria and the cementing media in the UPVC pipe for 3 days, the pipe is to be removed and mould is to be taken and at a temperature of 70 to 100°C in the oven and let it to be dry. For eg: 100 to 110°C in the oven may tends to be failure, after that it should be test in unconfined compression machine with the vertical load is applied at a rate of 1.25mm/min. The typical soil samples after failure in the unconfined compression machine test. [15]

5.2.3 Ph Test for Sand

The ph. test for sand specimen with different proportions of *Bacillus megaterium and Bacillus mycoides*were determined by IS code 2720-26. About 30g of sand sample was taken in a 100ml beaker, and then 75ml of bacteria solution was added to that sand same and the sand-water suspension stirred using a mechanical stirrer for about 15min. Then it is covered and allowed to stand for 12h. Then the ph. value was measured using a calibrated ph. meter. The final ph. values arrived as the average of the measurements of the soil samples. [16]

5.2.4 Calcium Carbonate Content Test

The calcium carbonate content of the sand after bacterial treatment was determined as per IS 2720-Part XXIII. The calcium carbonate content of soil is determined by treating 5g of dried soil specimen with hydrochloric acid is enclosed in a reactor vessel. Five grams of bacteria treated soil is to be taken and transferred to 150ml beaker. Then the 100ml of hydrochloric

solution is to be added. The beaker is covered with a watch glass and stirred vigorously several times for 1 hour may be respectively. After settling 20ml of supernatant liquid is to be added was pipped off and poured into a conical flask. To this solution 6 to 8 drops of bromothymol blue indicator is to be added and titrated with sodium hydroxide solution. The molarity used in this research was 0.75M may be respectively. [17]

6. SEM with EDX Analysis

Using EDX may quickly generate the information about the chemical composition of a sample, including the elements are present as well as a distribution and concentration. With a SEM, a variety of signals offer up different information about a given sample. The microstructure and the major elemental constituents of treated and the untreated soils were determined by using a SEM and EDX. The air-dried specimen is sieved through the 75mm micron sieve. About 10 to 15g of soil comprising fine clay fraction was thoroughly mixed with 1 L of sodium hexametaphosphate solution followed by a sedimentation process. After completing the sedimentation process, the soil suspension was air dried and crushed to make it as a powdered particle. The collected suspension particles were then centrifuged to separate the clay fraction of size less than 2μm and used for micro structural analysis. After the soil specimen preparation for this process was carried out on the soil samples using ICON-ESEM QUANTA 200.

7. Results and Discussions

By using the bacteria *Bacillus megaterium and Bacillus mycoides*to gain the strength of the soil sample by sing the different molarities as 0.25, 0.5, 0.75, 1.0 in this clayey soil by the mixture of the banana content may gain the strength with the less moisture content and by using these bacteria *Bacillus megaterium and Bacillus mycoides*may give the additional strength .(kulanthia et al 2022) done the same process by using both the egg cell and the calcium carbonate to increases the soil capacity by using the nutrient broth and it reduces the moisture content and from his research 0.5 molarity has more strength when compared to the other molarities in 3 day test. So, the same research is repeated here by using Luria broth miller and it is like that of the nutrient broth by using pure lime in this process may be respectively. And this test for comparison between the bacteria Bacillusmegaterium and Bacillus mycoides.

So same as the previous research may one of the molarity may give more compression strength by using the UCS machine. By using the agricultural waste banana fibre may gain the strength of the clayey sample.

Fly ash, rice husk is also the agricultural waste may use in the MICP process may be respectively. Silty clayey sample may use in the test same loamy clay are also us for this test to increase the strength. This may mainly use for the ground improvement process and the construction purpose.

8. Conclusion

The test result indicates that the application of Bacillus megaterium and Bacillus mycoides along with the various molarities of lime cementing chemicals enhances the UCS and reduces the permeability of sand.The increase of UCS and reduction in permeability were attributed to the generation of calcium carbonate between the sand particles through the bio cementation process. The addition of cementing chemicals may enhance the UCS and reduce the permeability of sand. As per the results the molarities of 0.25, 0.5, 0.75, 1.0 one of them may shows the high compression strength by using the unconfined compressive strength with the help of the cementing media by using the Luria broth process. Big advantage by using an agricultural waste as a banana fibre may tends to increase the strength. Same as the process grape seed may grow in the loamy soil, in this soil the grape seed may gain more strength, and this is one of the agricultural wastes. By testing loamy soil, the grape seed is a fine ingredient, if it is possible to make powder it can be used in the loamy soil for increasing the strength in this process.

References

[1] Bessadok, A., Roudesli, S., Marias, S., Follian, N., Lebrun, L., (2009) Alpha fibres for unsaturated polyester composites reinforcement: Effects of chemical treatments on mechanical and permeation properties, Composites part A, Applied Science and Manufacturing, 184-195. https://doi.org/10.1016/j.compositesa.2008.10.018

[2] Prochazka, P., Trckova, J., Dolezel, V., (2010) CementMixture Reinforced by Polypropylene Fibers at High temperature conditions. In Proceedings of the 35 Conference on our world in Concrete and Structures, Singapore, 2527.

[3] Selvakumar, S., Kulanthaivel, P., Soundara, B.J.N.F.E.E., (2021) Influence of nano-silica and sodium silicate on the strength characteristics of claysoil'.Nano technology Environmental Engineering, 6(3) 46. 1–10. https://doi.org/10.1007/s41204-021-00142-z

[4] Yasuhara, H., Neupane, D., Hayashi, K., Okamura, M., (2012), Experiment sand predictions of physical properties of sand cemented by enzy-matically-induced carbonate precipitation.Soils and Foundations, 52(3), 539–549. https://doi.org/10.1016/j.sandf.2012.05.011

[5] Kim, D., Park, K., (2013) an environmentally friendly soil improvementtechnologywith microorganism. International Journal of Railway, 6(3), 90-94. https://doi.org/10.7782/IJR.2013.6.3.090

[6] Gowthaman, S., Iki, T., Nakashima, K. Ebina, K., Kawasaki, S., (2019a)'Feasibility study for slope soil stabilization by microbial induced carbon at precipitation (MICP) using in digenous bacteria isolated from cold subarctic region'. SN Applied Sciences.1, 1-16. https://doi.org/10.1007/s42452-019-1508-y

[7] Choi, S.G., Wu, S., Chu, J., (2016) Bio cementation for sand using an egg shell as calcium source ,Journal of Geotechnical Engineering, 142(10), 06016010. https://doi.org/10.1061/(ASCE)GT.1943-5606.0001534

[8] Zhao, Q., Li, L., Li, C., Li, M., Amini, F., Zhang, H., (2014) Factors affect-ing improvement of engineering properties of MICP-treated soil catalyzed by bacteria and urease ,Journal of Materials in Civil Engineering, 26(12) , 04014094. https://doi.org/10.1061/(ASCE)MT.1943-5533.0001013

[9] Sidik, W.S., Canakci, H., Kilic, I.H., Celik, F., (2014) Applicability of bio cementation for organic soil and its effect on permeability. Geomechanics and Engineering, 7(6), 649–663. https://doi.org/10.12989/gae.2014.7.6.649

[10] Lin, H., Suleiman, M.T., Brown, D.G., KavazanjianJr, E., (2016) Mechani-calbehavior of sands treated by microbially induced carbonateprecipitation. Journal of Geotechical Geoenvironmental Engineering, 142(2), 04015066. https://doi.org/10.1061/(ASCE)GT.1943-5606.0001383

[11] Zamani, A., Montoya, B.M., (2017) Shearing and hydraulic behaviour of MICP treated silty sand. In Geotechnical Frontiers, 290-299.

[12] Soon, N.W., Lee, L.M., Khun, T.C., Ling H.S., (2013) Improvements in engineering properties of soil through microbial-induces precipitation, KSCE Journal of Civil Engineering, 17(4), 718–728. https://doi.org/10.1007/s12205-013-0149-8

[13] Omoregie, A.I., Ngu, L.H., Ong, D.E.L., Nissom, P.M., (2018) Low-cost cultivation of Sporosarcina pasteurii strain in food-grade yeast extract medium for microbially induced carbonate precipitation (MICP) application. Biocatalysis and Agricultural Biotechnology, 17, 247-255. https://doi.org/10.1016/j.bcab.2018.11.030

[14] Sharma, M., Satyam, N., Reddy, K.R., (2019) Investigation of various gram-positive bacteria for MICP in Narmada Sand, India. International Journal of Geotechnical Engineering, 15(2), 220-234. https://doi.org/10.1080/19386362.2019.1691322

[15] Gowthaman, S., Mitsuyama, S., Nakashima, K., Komatsu, M., Kawasaki, S., (2019b) Bio geotechnical approach for slope soil stabilizationusing locally isolated bacteria and inexpensive low-grade chemicals: a feasibility study on Hokkaido expressway soil, Japan. Soil sand Foundations, 59(2), 484–499. https://doi.org/10.1016/j.sandf.2018.12.010

[16] Kulanthaivel, P., Soundara, B., Das, A., (2020) Performance study on stabilization of fine-grained clayey soils using calcium source producing microbes. KSCE Journal of Civil Engineering, 24(9), 2631–2642. https://doi.org/10.1007/s12205-020-2028-4

[17] Gowthaman, S., Nakashima, K., Kawasaki, S., (2021) Effect of wetting and drying cycles on the durability of bio-cemented soil of express way slope. International Journal of Environmental Science and Technology, 19(4), 2309-2322. http://dx.doi.org/10.1007/s13762-021-03306-1

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