IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Application of calcite precipitation method to increase the shear strength of peat soil

To cite this article: E M Pratama *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **871** 012058

Application of calcite precipitation method to increase the shear strength of peat soil

E M Pratama[1*], H Putra[1], and F Syarif[2]

[1]Department of Civil and Environmental Engineering, IPB University, Bogor, Indonesia 16680
[2]Department of Civil Engineering, Universitas Islam Riau, Riau, Indonesia, 28284

*E-mail: era_mulia24@apps.ipb.ac.id

Abstract. The organic elements in the peat soil promote the fibrous texture and high moisture content. As a result, it has high compressibility density, shear strength, and low bearing capacity. Several methods of peat soil improvement have been implemented but are less environmentally friendly. The calcite precipitation method is one of the alternative sustainable methods by depositing calcium carbonate ($CaCO_3$). Soybean flour is used for the hydrolysis of urea, which causes the supply of calcium ions to precipitate calcium carbonate. The optimum composition of grouting solution consisting of 1 mol/L of reagent and 15 g/L and soybean is mixed into the soil. The shear strength parameters, namely the undrained shear strength (Cu) and internal friction angle, were evaluated by direct shear test. Soil with the treated solutions obtains Cu and internal friction angle of 49 kPa and 34°, respectively. On the other hand, Cu and internal friction angle have increased from the soil untreated soil by 34 kPa and 19°. This study elucidated that the calcite precipitated method have a great potential to improve the shear strength of organic soil.

1. Introduction

Peat soil is a soil whose main constituent consists of the remains of half-decayed plants. Indonesia is one of the countries with the most extensive peatlands globally, with a peatland area of 14,905,574 Ha [1]. Organic elements in the peat soil promote the texture fibrous and have considerable water content. However, peat soil has high compressibility and low specific gravity, density, shear strength, bearing capacity [2]. Hence, the peat soil is not suitable for constructing civil engineering structures, buildings, and roads. Therefore, many efforts are needed to increase the carrying capacity of peat soil and become a fundamental issue in Indonesia's infrastructure development.

Several methods of peat soil improvement have been introduced in the previous study, such as replacement method, mini woodpile, corduroy, preloading, and lime. A lime content of 5% was reported to improve the strength of peat soil [3]. In addition, the peat soil improvement method using cement significantly reduces soil permeability due to the rapid setting of cement, thus blocking groundwater flow [4]. Therefore, it may also promote environmental issues. Hence, improving soil properties should be considered to strengthen peat soil's soil strength and bearing capacity. One of the potential stabilizing methods to treat the peat soil is the precipitation of calcium carbonate method [5]. Calcite precipitation is one of the most widely developed calcite-induced precipitation methods (CIPM). This method is a soil strengthening technique using an enzyme urease to break down urea into ammonium ions (NH^{4+}) and carbonate ions (CO_3^{2-}). These carbonate ions will react with calcium ions (Ca^{2+}) to form calcite ($CaCO_3$) [6]. CIPM is a soil improvement method that is environmentally friendly, sustainable and increases soil shear strength parameters. CIPM improves soil shear strength up to 20% and significantly reduces soil permeability in organic soils compared to without CIPM. CIPM is generally used as an improvement method in sandy soils and has been shown to increase the shear strength of soils between 400 kPa to 1.6 MPa depending on the amount of calcite deposit formed [7].

This study aims to evaluate and optimize the application of the calcite precipitation method to improve the soil shear strength parameters of peat soil. A test-tube experiment assessed the amount of calcite precipitate formed to obtain the optimum composition. Thus, they are applied to the peat soil by a mixed method. The soil shear strength parameters (e.g., cohesion and internal friction angle) were tested through direct shear equipment.

2. Materials and Method

2.1. Materials

The material used in this research is peat soil originating from Riau, Indonesia; urea ($CO(NH_2)_2$, 95% purity) produced by Ajax Finechem Pty. Ltd., calcium chloride ($CaCl_2$, 95% purity) made by Loba Chemie Pvt. Ltd., distilled water. In addition, soybean flour in food-grade obtained from Gasol is used as the bio-catalyst in this study.

2.2. Peat soil properties test

This test was carried out to obtain the value of the water content of the peat soil, testing the density of soil particles, analyzing the grain size of the soil, testing the organic and ash content, as well as the Atterberg limit of the soil sample. The soil properties test and standard used in this study are depicted in Table 1.

Table 1 Peat soil properties test

Test	Standard	Method
Water content	ASTM D2216 - 19	Standard test methods for laboratory determination of water (moisture) content of soil and rock by mass
Specific gravity	ASTM D0854	Standard test methods for specific gravity of soil solids by water pycnometer
Organic content and ash content	ASTM D2974 - 14	Standard test methods for moisture, ash, and organic matter of peat and other organic soils
Atterberg limit	ASTM D4318-84	Standard test methods for liquid limit, plastic limit, and plasticity index of soils
Grain size	ASTM D6913	Standard test methods for particle-size distribution (gradation) of soils using sieve analysis

2.3. Test-tube experiment

A test-tube experiment was conducted to determine the optimum composition of the reagent and soybeans that can form calcite ($CaCO_3$). Calcite deposition was evaluated in polypropylene (PP) tubes [6]. The evaluation was carried out with the difference before being filtered and after being filtered in oven-dry conditions. Filtering is done using filter paper. This test is carried out by obtaining the reagent and soybean mixture composition. Variations in soybean content used in this test are 1 g/L, 5 g/L, 10 g/L, 15 g/L, and 20 g/L. The experimental condition of the test-tube experiment is shown in Table 2.

Table 2 Reagent and soybean concentration

Case	Soybean concentration (gram/L)	Reagent concentration	
		Urea (mol/L)	$CaCl_2$ (mol/L)
A	1	1	1
B	5	1	1
C	10	1	1
D	15	1	1
E	20	1	1

Test-tube experiment procedures adopt the method developed by Putra [8] and Neupane [6]. First, reagents and soybeans were prepared. Then, the reagent and soybean powder were mixed with distilled water and stirred for 5 minutes, separately. Furthermore, the soybean solution mixed with distilled water is filtered using a sieve number200 with the opening of 0.075 mm to obtain a pure soybean solution. The reagent and soybean solution were mixed in a centrifuge tube with a total volume of 30 ml. Thus, the samples are stored for seven days curing times. After that, the sample was dried at a temperature of 60˚C for 24 hours, and then the mass was weighed. The highest mass of calcite formed was used as the basis for determining the optimal soy flour content. Determination of the optimum levels of organic matter is carried out in the same way as determining the levels of reagents and optimum soybeans after knowing the optimum range of soybeans. The illustration of the test-tube experiment is shown in Figure 1.

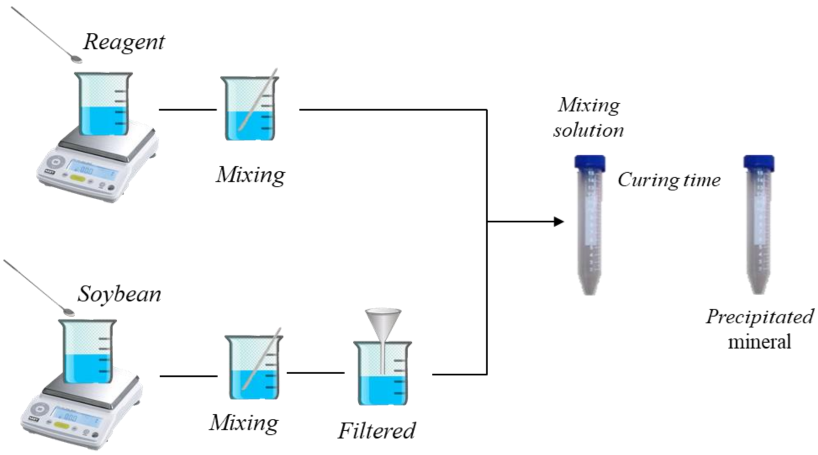

Figure 1. Schematic of the test-tube experiment

2.4. Shear strength test of peat soil
A direct shear test is conducted to obtain the soil shear strength parameter, namely cohesion (c) and the internal friction angle (φ) [9]**.** This study uses a direct shear test based on the ASTM 3080-90 test standard on soil's direct shear test method. Shearing rate used is 0.2 mm/minute. Soil samples were tested with 100% saturation degree wet state. Soil conditions under test are undrained conditions. The schematic of the direct shear test is described in Figure 2. Peat soil was prepared in two conditions, namely treated and untreated soil. The dry density of the soil used is 0.6. First, the normal force is applied over the shear box. Then a shear force is applied to provide shear in the center of the test object (1/2 height of the soil sample).

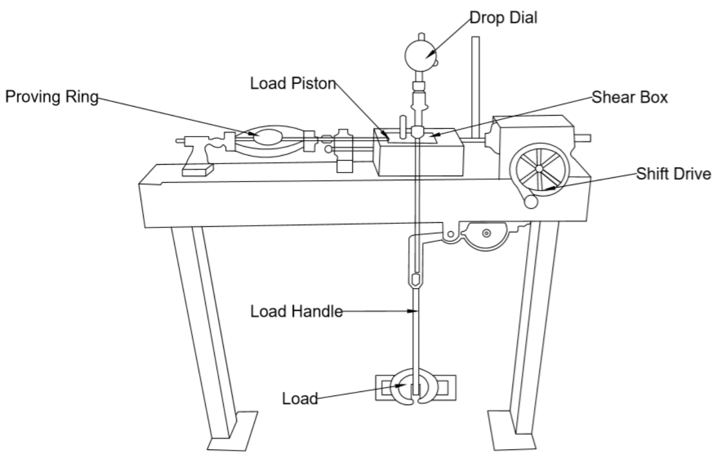

Figure 2. The schematic of the direct shear test

3. Results and Discussion

3.1. Peat soil properties

The peat soil sample is classified as organic soil according to ASTM 4427-92, with an organic content of 75.51%. Organic soil is soil with organic matter content in the range of 25%-75% [10]. Peat soil has an ash content value of 26.48%, classified as high ash according to ASTM D2974. The ash content and organic content are inversely related, where if the ash content is low, the organic content is high. The moisture content of 51.85% is classified as slightly absorbent according to ASTM D2980. Slightly permeable is peat soil with the ability to store and absorb water less than 300% [11]. Peat soil has a specific gravity value (Gs) of 1.07. Based on J.Bowles [12], Soil with a Gs value of 1.0-2.6 is classified as organic soil (peat). The liquid limit (LL) of peat soil is 95.57%, and the peat soil in this study is not plastic. The Atterberg limit of organic soils depends on two opposing characteristics: the high water absorption capacity of the organic matter and the particle aggregation of the organic matter [10]. The results of testing soil properties is depicted in Table 3.

Table 3. Peat soil properties

Soil properties	Value	Unit
Water content	51.85	%
Specific gravity (Gs)	1.07	-
Organic content	75.51	%
Ash content	26.48	%
pH	3.19	-
Liquid limit (LL)	95.57	%
Soil type	Organic	-

Soil grain size analysis is shown in a graph of the relationship between grain size or sieve diameter and the cumulative pass percentage, also known as a grain size distribution graph. To determine the gradation of a soil sample by calculating the uniformity coefficient (Cu) dan gradation coefficient (Cc). Cu and Cc based on the relationship between D_{10}, D_{30}, dan D_{60} defined as 10%, 30%, 60% of the weight of the total grain size with a diameter smaller than sure grain size. The uniformity coefficient (Cu) and gradation coefficient (Cc) obtained are 4.33 and 1.25. Therefore, based on the ASTM C136-06 classification system, if the value of Cu is greater than 4 and Cc between 1 and 3, then the type of peat soil is fine sand with the symbol SW. The graph of the grain size distribution in Figure 3.

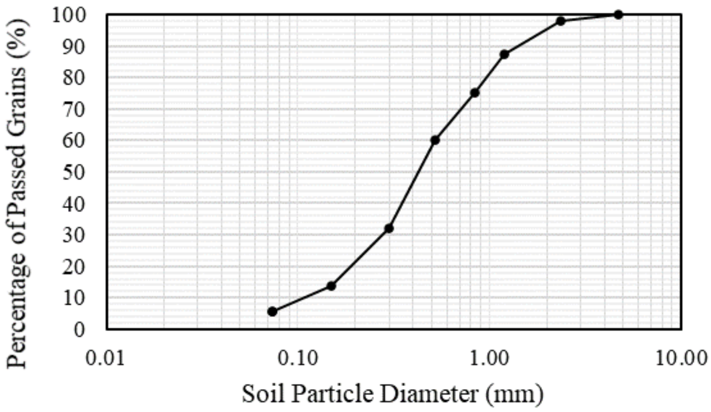

Figure 3. Grain size distribution chart

3.2. Test-tube experiment

Calcite deposition was evaluated directly by the test-tube method. This method uses a transparent PP tube to observe the mass of calcite from the reagent and variations of soybean concentration. The test-tube test result is shown in Figure 4.

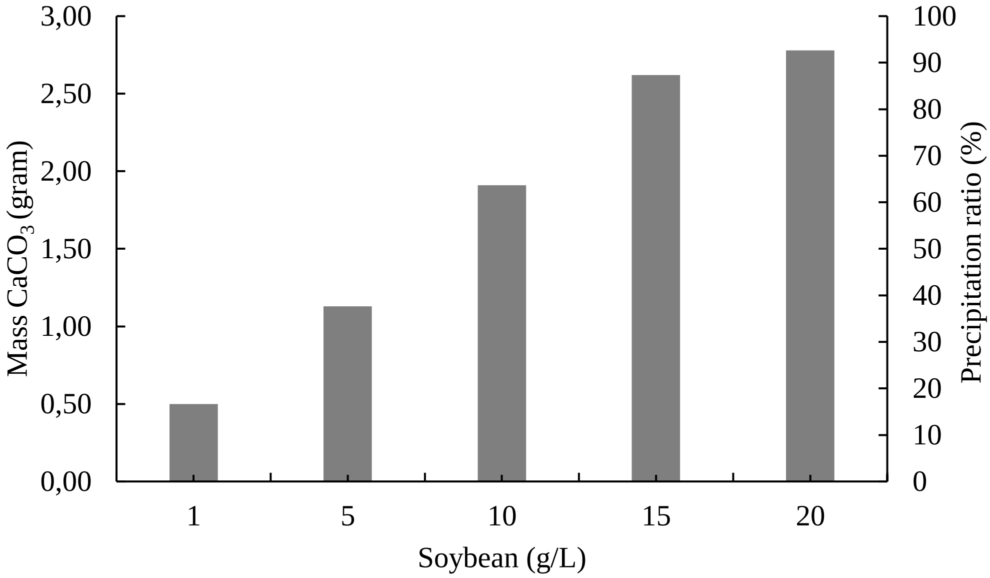

Figure 4. Test-tube experiment results

Figure 4 shows that the increase of soybean content promotes higher calcite mass. Soybean concentration of 15 g/L results in an optimum calcite mass of 2.62 grams. The concentration of soybean 20 g/L produced the highest calcite mass of 2.78 grams, while the content of soybean flour 1 g/L produced a mass of at least 0.5 grams of calcite. The highest precipitation ratio difference occurred between soybean content of 10 g/L and 15 g/L by 23% compared to the difference in precipitation ratio between soybean content of 15 g/L and 20 g/L of 5%. The test-tube results showed that the difference in calcite mass-produced between 10 g/L and 15 g/L soybean flour was 0.71 grams, while the difference in calcite ready-made between 15 g/L and 20 g/L soybean flour was 0.16 grams. Based on this, the content of soybean flour used in the calcite precipitation method is 15 g/L of soybean flour. Therefore, the amount of calcite mass-produced using pure soybean can replace the urease enzyme in the Enzyme

IOP Conf. Series: Earth and Environmental Science **871** (2021) 012058 doi:10.1088/1755-1315/871/1/012058

Induced Calcite Precipitation (EICP) technique, which is not much different from that carried out R.A. Zulfikar *et al* [13] reported that soybean able to replace urease in the formation of $CaCO_3$. This result is proven by Pratama [14] showed that the urease activity produced by soybean flour with a concentration of more than 10 g/L was sufficient to replace the urease enzyme in the Enzyme Induced Calcite Precipitation (EICP) technique. XRD and SEM confirmed these results in looking at the composition of the material in producing $CaCO_3$ and carbonate images formed. XRD and SEM results by Pratama [14] showed that the presence of calcite formed due to the hydrolysis of the reagent by soybean. This research uses soybean flour as a substitute for urease enzyme in precipitation $CaCO_3$.

3.3. Direct shear test

The treatment soil was subjected to direct shear testing after 14 days. This research uses the premixing method in making samples. The premixing procedure is carried out by mixing the repair solution or grouting solution with a soy flour content of 15 g/L and soil sample according to a predetermined density of 0.6 g/cm^3. This study aims to see the effect of the calcite precipitation method on the shear strength of peat soil. The value of undrained shear strength (Cu) and internal friction angle is shown in Figure 5. Figure 5 shows that Cu of the untreated soil is 34 kPa and the internal friction angle is 19°.

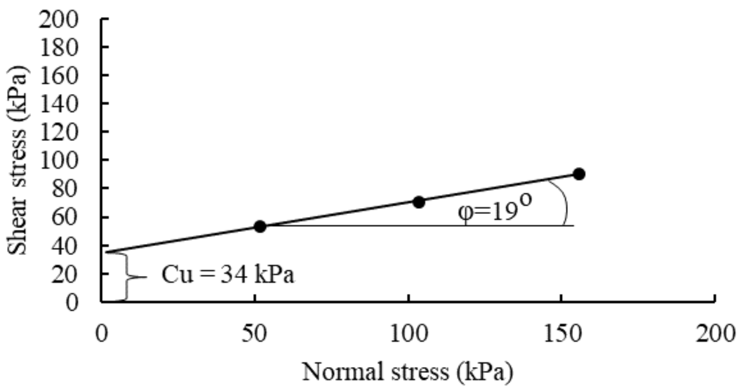

Figure 5. Cu and internal friction angle in untreated soil

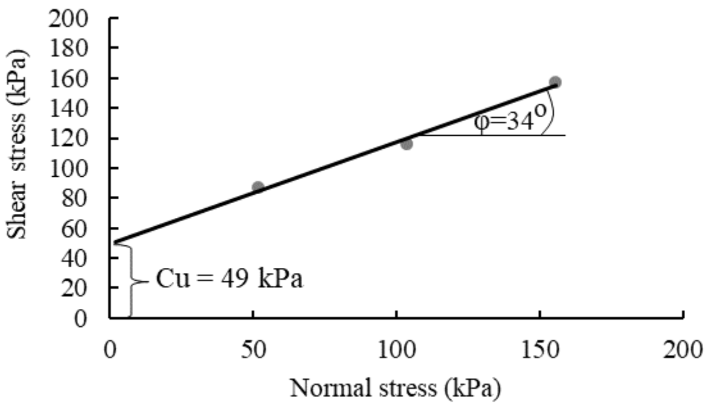

Figure 6.
Cu and internal friction angle in treated soil

The direct shear test results on untreated soil and treatment soil, there was an increase in the undrained shear strength (Cu). The undrained shear strength of peat soil increased from 34 kPa to 49 kPa after treating by mixing solution. In addition, the friction angle is also increased from 19^o to 34^o. The increase occurred due to the role of soybean, which can accelerate the reagent reaction to produce calcite. The bond between peat soil and calcite is one of the things that can increase the cohesion in the soil [15]. The increase in soil strength obtained through the calcite precipitation method is influenced by the calcite content and the position of the calcite formed in the soil. The previous research reported by Putra[16] said that the strength of the improved soil was directly proportional to the calcite content in the soil. However, compressive strength can be achieved at low calcite content if the calcite is formed to become bonds between soil grain particles. The increase occurred when the calcite formed fill empty spaces or voids in soils with high organic content [17]. Theoretically, the premixing form can increase the mass of calcite or carbonate deposited. The number of pores in the soil is not limited by the premixing method in this study because the soil sample and the repair solution or grouting solution have been mixed first and then compacted in the mold or test specimen mold. This research does not use injection that has been applied to sandy soil with the calcite precipitation method. H.Putra *et al*[18] proved that the injection method can increase the strength of sand with poor gradations with the calcite precipitation method, an increase in power occurs, which is tested by the Unconfined Compressive Strength (UCS) test reaching 555 kPa. The carbonate that functions as a binder between particles is formed with a short distance between the particles [19]. The results obtained in this study were quite good compared to the microbacterial induced calcite precipitation (MICP) method on peat soil as done by Silvakumar *et al* [20] who got UCS results of more than 100 kPa after 28 days while in this study the UCS value was more than 100 kPa if direct shear strength results have been converted to UCS values for 14 days.This result indicates that $CaCO_3$ precipitation occurs in organic soils. However, the amount of $CaCO_3$ relatively less in organic soils than in sandy soils [21]. The increase in carbonates in peat soils is meager at only 8% compared to sandy soils at 35% [17].

4. Conclusion

A series of experiments have been conducted to obtain the optimum composition of soybean for the calcite precipitation method and its applicability in improving the shear strength of peat soil. Soybean with a 15 g/L is selected and applied to the soil sample with a mixing method. The direct shear test result shows a significant improvement of shear strength parameters of peat soil after treating by mixing solution. An improvement of undrained shear strength (Cu) from 34 kPa to 49 kPa and internal friction angle from 19^o to 34^o were obtained in this study. This study concludes that calcite precipitation using soybean as bio-catalyst is a potential method to improve the strength of peat soil.

Acknowledgment

This research was funded by the Ministry of Education, Culture, Research, and Technology of Indonesia, grant number 1/E1/KP.PTNBH/2021.

References

[1] N. E. Yulianto, F.E. Mochtar 2012 Behavior of Fibrous Peat Soil Stabilized with Rice Husk Ash (RHA) and Lime, *Proceedings of 8th International Symposium on Lowland Technology* (Bali) vol 1 pp. 1-5

[2] W. Rahayu, D. Damoerin, A. Hayyan 2018 The Effect of Geopolymers to Increase the Shear Strength of Peat Soil *Journal of Civil Engineering* **25 3** 187

[3] F. V. Riza, I. A. Rahman, A. M. A. Zaidi 2011 Possibility of Lime as a Stabilizer in Compressed Earth Brick (CEB) *Int. J. Adv. Sci. Eng. Inf. Technol* **1 6** 582

[4] D. Mujah, M. A. Shahin, L. Cheng 2017 State-of-the-Art Review of Biocementation by Microbially Induced Calcite Precipitation (MICP) for Soil Stabilization *Geomicrobiol. J.* **34 6** 524–537

[5] Z. A. Rahman, N. Sulaiman, S. A. Rahim, W. M. R. Idris, T. Lihan 2016 Effect of cement

IOP Conf. Series: Earth and Environmental Science **871** (2021) 012058 doi:10.1088/1755-1315/871/1/012058

additive and curing period on some engineering properties of treated peat soil *Sains Malaysiana* **45 11** 1679–1687
[6] D. Neupane, H. Yasuhara, N. Kinoshita, and Y. Ando 2015 Distribution of mineralized carbonate and its quantification method in enzyme mediated calcite precipitation technique *Soils Found* **55 2** 447–457
[7] H. Yasuhara, D. Neupane, K. Hayashi, M. Okamura 2012 Experiments and predictions of physical properties of sand cemented by enzymatically-induced carbonate precipitation *Soils Found* **52 3** 539–549
[8] H. Putra, H. Yasuhara, N. Kinoshita, A. Hirata 2017 Optimization of enzyme-mediated calcite precipitation as a soil-improvement technique: The effect of aragonite and gypsum on the mechanical properties of treated sand *Crystals* **7 2** 1–15
[9] S. A. Nugroho, A. I. Putra, R. Ermina 2012 Soil Shear Strength Parameter Correlation Result of Triaxial Test and Unconfined Compressive Strength (UCS) **11 1** 1–10
[10] A. Desiani 2019 Study of the Effect of Organic Matter on Physical Properties of Soft Soil *Journal of Civil Engineering* **13 1** 21–48
[11] N Ajie, R Respati 2018 Palangka Raya Peat Stabilization with Non-Organic Soil and Lime Mixed Materials *Civil Engineering Scientific Media* **6 1** 124–131
[12] J. Bowles 1992 Engineering properties of soils and their measurement in *McGraw-Hill, Inc.*, Vol 4, Ed J. Bowles (New York:McGraw-Hill) pp 215
[13] R. A. Zulfikar, H. Putra, H. Yasuhara 2020 Utilization of Soybean as Catalyst Material in Enzyme-Mediated Calcite Precipitation (EMCP) for Crack Healing Concrete *J. Civ. Eng. Forum* **1 11** 1–11
[14] G. B. S. Pratama, H. Yasuhara, N. Kinoshita, H. Putra 2021 Application of soybean powder as urease enzyme replacement on EICP method for soil improvement technique," *IOP Conf. Ser. Earth Environ. Sci.* **622 1**
[15] R. Mackevičius, D. Sližyte, T. Zhilkina 2017 Influence of Calcite Particles on Mechanical Properties of Grouted Sandy Soil *Procedia Eng* **172** 681–684
[16] H. Putra, H. Yasuhara, N. Kinoshita 2017 Optimum condition for the application of enzyme-mediated calcite precipitation technique as soil improvement method *Int. J. Adv. Sci. Eng. Inf. Technol* **7 6** 2145–2151
[17] H. Canakci, W. Sidik, I. Halil Kilic 2015 Effect of bacterial calcium carbonate precipitation on compressibility and shear strength of organic soil *Soils Found* **55 5** 1211–1221
[18] H. Putra, H. Yasuhara, N. Kinoshita 2017 Applicability of natural zeolite for NH-forms removal in enzyme-mediated calcite precipitation technique *Geosci.* **7 3** 1-14
[19] K. Rowshan Bakht, M. Khamehchiyan, R. H. Sajedi, M. R. Nikudel 2016 Effect of injected bacterial suspension volume and relative density on carbonate precipitation resulting from microbial treatment *Ecol. Eng.* **9 89** 49–55
[20] S. Gowthaman, M. Chen, K. Nakashima, S. Kawasaki 2021 Effect of Scallop Powder Addition on MICP Treatment of Amorphous Peat **9** 1–13
[21] W. Sidik, H. Canakci, and F. Celik 2013 Effect of Particle Size of Sandy Soil on Bacterial Calcium *Geoteknik Sempozyumu* **1 1** 5-7