Microbially induce calcite precipitation as bio grouting by bacillus subtilis on its shear strength parameter effects on organic soil (peat) from Siak Regency Riau Province Indonesia

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Abstract. Contemporarily, the use of bacterial Calcite precipitation (bio grouting) is popular as a ground improvement technique for sandy soil. However, this was not frequently applied to organic or peat variety. Meanwhile, on the island of Sumatra, the province with the largest peat terrain is Riau, expanding an area of ± 4.04 million Ha, which is 56.1% of the total mulch land in the region, where Siak is one of the districts, possessing a fairly large portion. Furthermore, numerous problems ensue due to this structure, especially during the construction of infrastructure. Therefore, this study focused on bacterial Calcite precipitation from Bacillus Subtilis, and its effect on the Shear Strength parameters of organic soil, where a special injection system was prepared for inducing the bacterial solution to the samples, which were tested by UCS tool, in order to ascertain shear strength parameter, after 3 days. Moreover, through this research, it is hoped that the technique adopted improves engineering performance, especially in the areas of increasing shear strength parameters of organic or peat soil. Hence, this procedure is suitable and also assists in reducing challenges in construction of infrastructure within Siak district

1. Introduction
Indonesia contains 20 million hectares of peat land, placing it number four on the category of largest land proprietor in the world, after Canada, Russia and America. Furthermore, its distribution is in four large islands, namely Sumatra (35%), Kalimantan (32%), Sulawesi (3%) and Papua (30%) [1]. Specifically on the Sumatra islands, these terrains are usually found in the lowlands, along the east coast, with an area of 7.2 million hectares, hence Riau is identified as the Province with the widest peatland, with an area of ± 4.04 million Ha or 56.1% of the total area [2].

Research reported that within the past 18,000 years its formation commenced in south-east Asia, while in Indonesia, it was said to have developed at about 5,000 to 8,000 years ago, occurring in areas that have long been submerged in water [3]. They have both physical and technical properties that do not benefit civilian buildings, which include water content (Wc) that reaches 900%, the small weight of soil volume (0.8 - 1.04 gr/cm³), large number of pores, ranging from 5-15, and high organic content > 75% [2, 4].

The American Standard of Testing and Material (ASTM) reported that peat is a soil possessing over 75 % natural substance, commonly shaped under anaerobic conditions, through the activity of
organisms, microorganisms, and concoction mixes on plant remains. In addition, the soil normally contains exceptionally high water and mineral content upon examination. Furthermore, many nations around the world have this material covering a generous area, often termed tropical land [5]. These unfavorable physical properties automatically influence the behavior of peat soil techniques, as it is known to have a very low carrying capacity of 57 kPa [4], as well as large and uneven compression capable of damaging numerous civil buildings [2, 4].

Organic soils found in numerous locations worldwide, are often a mixture of finely divided particles of organic matter, which in some instances may contain visible fragments of partly decayed vegetables substances and shells. Moreover, their amount in soil significantly affects geotechnical properties, including specific gravity, water content, liquid and plastic limits, density, hydraulic conductivity, compressibility, and strength. Therefore, in order to improve these, different enhancement techniques were used [6].

Microbiologically instigated calcium carbonate (CaCO$_3$) precipitation (MICP) is a biogeochemical procedure where calcium carbonate precipitation is prompted in the dirt network. This has been proposed as a manageable cementation procedure for soil improvement, while increments in shear quality, unconfined compressive quality, solidness, and liquefaction opposition were accounted for, due to the presence of calcium carbonate precipitation, due to microbial movement. Hence, this procedure likewise offers an elective remedy for a wide range of structural issues. Research center tests have demonstrated that MICP possess the capacity to immobilize follow metals and radionuclides, through co-precipitation with calcium carbonate. Additionally, it has also appeared to improve the undrained shear reaction of soils, offering potential advantages over current improvement systems that may subsequently present natural dangers as well as the ill effects of low "assurance of execution" [7].

The use of bacterial in this technique, also known as cementation, has been adopted in the assortment of geotechnical building applications, e.g., splits fix in stone and concrete, upgrading the bearing limit of soil, pore and molecule restricting filling, as well as diminishing porousness. Furthermore, within the significant part of prior biocementation applications, microscopic organisms termed Bacillus pasteurii assumed a significant role in CaCO$_3$ precipitation. This shows a high urease generation, promoting its utility in microbial calcite processes in numerous examinations [7].

In addition, Microbially Induced Calcite Precipitation (MICP)/Bio Grouting have been studied as an alternative method of improving soil engineering properties. Meanwhile, free increase in compressive strength, ranging from 400 kPa to 1.6 MPa, depends on the amount of calcite deposits achieved, while its permeability decreases by more than one order of magnitude [8].

Aside water, cementitious materials are the most devoured substances on Earth. Therefore, they ought to be concentrated, in order to show acceptable execution, concerned with the performance of a few works in an attempt to improve the materials’ mechanical properties. Furthermore, in the perspective of developmental challenges on improving their attributes and toughness, augmentations of microscopic organisms, including the class Bacillus, are being studied for break filling, thus, expanding compressive qualities, through calcium carbonate (CaCO$_3$) precipitation. Hence, conducting this process is likewise called biocementation, therefore, it ought to be noticed that microbes exist for billions of years, and a huge number of their biotechnological applications are not yet established. In addition, Albéits’ numerous specialists are keen on the experimentation of bioprecipitation of CaCO$_3$, although the entire procedure is not very clear and characterized. Meanwhile, microorganisms are capable of hastening calcium carbonate production through a few systems, the physiology and hereditary considerations required are perplexing and hard to comprehend. A few microorganisms with the capacity to create minerals were utilized in fixing limestone landmarks and also in filling pores and splits in concrete and various cementitious materials, capable of improving mechanical properties and toughness. Among the microbes utilized in the exploration on biocementation, the organism B. subtilis stands out, based on their ability to deliver calcite, a crystalline type of CaCO$_3$. This process is accelerated in the presence of a medium with a calcium source [8].
An enzyme-reagent mixed solution from bacteria (i.e., purified urease and CaCl₂-urea), produced the precipitated calcite after the chemical reaction, is injected into the soil. The precipitated calcite may provide bridges between the grains of sand, restricting their movement, and hence, improving the stiffness and the strength of the soil [6, 9]. A schematic of the whole process listed above and grouting mechanism expected are illustrated in figure 1.

Figure 1. Schematic of calcite precipitation process on EMCP technique [6].

From the description above, the purpose of the study includes:

- An initial research to examine the extent to which mixing a solution of Bacillus bacteria Subtilis, influences the stabilized organic soil.
- To find out the change in value parameters of strong shear in organic soils mixed with Bacillus bacteria Subtilis.

2. Material and method

2.1. Material
In this study is involved the use of reagents, e.g. CO (NH₂) urea, CaCl₂, and the microorganism, Bacillus Subtilis as a grouting material. In addition, the organic soil were from Siak Regency in Riau Province, classified as an OH type, with reference to Unified Soil Classification System (USCS) and A-7-5 in AASHTO Classification system seen in figure 2.
Figure 2. Grain Size Distribution of Organic Soil.

This is a pioneer research to ensure the effect of microbially induced calcite precipitation technique by bacteria (bacillus subtilis) takes place in organic soil. This was attempted with random concentrate amount of the material, therefore, creating samples as a form of MICP trial, as shown in the table below.

Table 1. Concentrate of the Reagen.

| No | Material          | Quantity |
|----|-------------------|----------|
| 1  | Bacillus Subtilis | 5 gr     |
| 2  | Urea (CO(NH)₂)   | 10 gr    |
| 3  | CaCl₂             | 10 gr    |
| 4  | Water             | 20 ml    |

This research utilized 10 % of reagent calculated from the weight of soil, making comparison with no reagent of the sample seen in figure 3.

Figure 3. The Sample of organic soil with the reagent.
2.2. Method
Two samples were made, one in 10 % concentrate, and the other was without the reagent. To evaluate applicability of MICP as a soil-improvement technique, the evolutions in the strength of the treated sample are examined through unconfined compressive strength (UCS) tests respectively. Soil specimens are prepared in cylinders and treated with concentration-controlled solutions composed of reagent. After the curing time, the treated specimens are removed from the cylinders. The surface of the treated samples is flattened before the UCS tests are conducted [6, 9]. The schematic of UCS test is illustrated in figure 4. Therefore, they were both placed on a desicator for 3 days, and subsequently evaluated with UCS test, as seen in figure 4.

![Figure 4. UCS Test for the sample.](image)

The UCS is one of the most commonly used rock engineering parameters for its mass classification, or strength determination. In addition, the mean value and its variability are often assumed to reliably represent material property, although it rarely represents the intact forms. Furthermore, the test simply records the collapse of load during uniaxial loading of a cylindrical specimen, and many suggested this assessment as an index, rather than simply a unique engineering parameter. Hence, it is a proxy for rock strength, dependent on the loading rate, specimen size, and other numerous factors. Furthermore, it is not the same as the Hoek-Brown strength criterion parameter $\sigma_{ci}$ [7].

3. Result and discussion
From the UCS test on two samples, this research obtains the result seen in figure 5 and figure 6.
The UCS test shows that the sample with 10% concentrate of reagent and the one without, had a compression strength of $q_u = 2.93 \text{ kg/cm}^2$ and $q_u = 4.97 \text{ kg/cm}^2$, respectively. Therefore, this result shows that the bio-grouting technique or microbially induced calcite precipitation with the concentrate had less compression strength than the other. This indicates the addition of some amount of water, of which the sample with reagent possesses a large quantity, which affected the compression strength.

Although calcite was precipitated in the organic soil, its strength was very different than that of the sand reported by [3, 10, 11]. The cementation with calcium carbonate in sandy soil binds the solid sand particles. However, the same calcium carbonate binds soft organic soil particles. When stress is applied to the sand sample, failure occurs either through strong calcite or sand particles. Therefore, high compressive strength is obtained in MICP-treated sandy soil [3, 10, 11]. On the other hand, failure occurs through weak organic particles or bonds between strong calcite and weak organic soil particles. Therefore, low strength is obtained in treated organic soil. Hence, it can be concluded that the failure of organic particles governs the strength of bio-cemented organic soil. For this reason, the strength obtained from organic soil is less than that obtained from sandy soil with same amount of calcite. This is also true for concrete. The compressive strength is controlled by both the strength of the aggregate and the strength of the paste, and it depends on which of these two fails first. Studies reported in the literature have shown that concrete containing organic content has lower strength. This is attributed to the failure of the weak points of the concrete matrix that are organic particles.

The amount of CaCO$_3$ was comparatively less in the organic soil than in the sandy soil [12]. This difference in calcite precipitation in organic soil and sandy soil can be attributed to soluble organic ligands and other organic matter that are well-known inhibitors of CaCO$_3$ precipitation and crystal growth. Researchers have related this inhibition mechanism to a number of factors. When the organic molecules are absorbed onto a mineral surface, they can either induce dissolution or impair crystal growth, depending on the saturation conditions. Other studies have proposed that the organic matter content prevents CaCO$_3$ precipitation by coating the existing CaCO$_3$ crystal surfaces, thus blocking their nucleation sites and preventing homogeneous crystal growth [13, 14].

In addition, further investigations ought to be conducted, in order to analyse this manifestation, which include water effect, pH, and amount of carbonate. Furthermore, organic soil possessed significant water content, and this should, therefore, be analysed in subsequent studies.
4. Conclusion and recommendation

4.1. Conclusion
Based on this research, the following conclusions can be inferred:

- This mix of concentrate made with a reagent had a lesser compression strength, in comparison with the sample that had no treatment.
- The applicability of the bio grouting technique in Organic soil requires the conduction of some investigation, in order to evaluate its effects in engineering and the physical properties of organic soil.

4.2. Recommendation
Several recommendations to be conduct in subsequent research include:

- Check the amount of carbonate made by the reagent.
- Examine the effect of particle bond in organic soil with the use of an SEM tools.
- Investigation of the effect of water content, pH and other aspects in the success of bio grouting Techniques, or microbially induced calcite precipitation.

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