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RESEARCH ARTICLE

Restoring The Permeability Of Peat Soil Using Sand-Mixed And Bio-Grouting Techniques Made From Bacteria

Gezan Jacob [1,*], Adhisti Davina[1], Tanner Ontario[1]

[1] *Soil Science, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.*

* Corresponding author : Jacobgezan88@gmail.com
Tel.:+1-647-817-2660;
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Abstract

Restoring the permeability of peat soil using a mixture of sand and bio-grouting techniques made from bacteria aimed to determine the effect of adding 5% sand by weight of dry soil and bacteria on the permeability of peat soil. Peat soil is a problem that is often encountered in the world of construction. Peat is a type of soil formed from the accumulation of half-decayed plant remains which causes it to have a high organic matter content.

The research testing method refers to ASTM (American Society for Testing and Materials) procedures and SNI. Preliminary testing, namely testing the original soil moisture content, testing the original soil specific gravity, and testing standard compaction (proctor test). Meanwhile, permeability testing was carried out using the falling head method. The original soil was taken at the location of Buana Makmur Village km 55, Dayun Sub District, Siak Regency, namely in the form of sand 5% of the dry weight of the soil, additional ingredients in the form of bacteria and CaCl2 and Uruea.

Based on the results of testing the physical properties of the original soil, it is known that the soil in Buana Makmur Village, km 55, Dayun Sub District, Siak Regency, is an original soil type with a water content of 407.5% and a specific weight (Gs) of 1.3 gr. Based on the results of the permeability test conducted, mixing 5% sand and adding 25% bacteria had the lowest permeability coefficient value compared to the original soil and sand mixed soil which had a permeability coefficient of K20oc = 1.166x10^{-3}cm/second.

Keywords: Bio-Grouting Technique, Stabilization, permeability, sand, *bacillus subtilis* bacteria

1. Introduction

1.1 Background

Peat soil is a type of soil that does not meet the requirements to be used as a base layer for highway construction because it has characteristics such as high organic content, low calcium content, and high shrinkage properties. Due to its high permeability value, peat soil requires experimental tests with the addition of sand and bacterial materials to use peat soil. This test aims to see the reaction produced by bacteria to peat soil. Bacteria were chosen because they can shrink to cover cavities in peat soil. Soil stabilization engineering was carried out to determine the effect of adding sand and bacteria on the permeability of peat soil. Peat is a type of soil that is formed from the accumulation of half plant remains which causes a high organic matter content. This type of soil is formed in wetlands and is called peat in English. In various parts of the world, peat soil is known by various names such as bog, moor, muskeg, pocosin, mire, and others. The term peat itself is absorbed from the regional language of Banjar.

Peat soil is a problem that is often encountered in the world of construction. Peat soils have a low carrying capacity and can cause large settlements when imposition occurs (Parlan et al., 2016).

Bio-grouting is a soil stabilization technology that involves the precipitation of calcium carbonate (CaCO3) by microorganisms. Calcium carbonate precipitation works as a binder between cells, stimulating cementation processes between soil grains. When using bio-grouting technology, the kind of soil to be stabilized and the type of microbe employed as a bio-grouting agent must be considered (Pangesti, 2005).

The ability of the soil to transmit water is referred to as soil permeability. Soils with high permeability can enhance infiltration rates, lowering water flow rates. Permeability is described qualitatively in soil science as the reduction of gases, liquids, or plant root penetration or passage (Syarif et al. 2020).

Bacillus is a gram-positive bacteria with an optimal temperature for growth between 25-35°C. Although Bacillus was considered to be strictly aerobic, it was discovered later that they can live anaerobically under defined conditions. *Bacillus subtilis* has a physiology that is relatively different from other bacteria that are not pathogenic, which is relatively easy to manipulate genetically and is also easy to breed so that it can be developed on an industrial scale (Soesanto, 2008).

Soil improvement which usually has the property of swelling and shrinking, such as peat soil, is carried out using soil stabilization methods, including soil stabilization using grouting methods which are not environmentally friendly and most are in the form of suspensions (cement, clay-cement, etc.) or emulsions (asphalt, etc.) (Xanthakos, 1994; Karol, 2003). All chemicals for bio grouting, except for sodium silicate and or dangerous (Karol, 2003: van Passsen, 2009).

2. Literature review

Several earlier studies on compressive strength, shear strength, organic soils, and the addition of sand to boost soil carrying capacity can be utilized as references in this study's discussion. Previous research was presented in this paper, specific research by Syarif et al (2020), Willy (2015), Angelina (2013), Waruwu (2013), Afriani (2008), and De Jong, J.T. (2006). Syarif et al (2020), has conducted research with the title "Application of the Biocementation Technique by *Bacillus subtilis* and Its Effect on Permeability in Organic Soils". Willy

(2015), conducted research on direct shear strength testing by mixing clay with sand with a mixture percentage of 10%, 30% 20%, 30%, and 40%. Lynda (2013), has conducted research with the title "Characteristics of Soil Shear Strength Using the Biogrouting Stabilization Method of *Bacillus subtilis* Bacteria". Waruwu (2013), conducted research on improving the compressive strength of peat soil due to preloading. Afriani (2008), researched the effect of adding sand to clay soil. According to the study's findings, the addition of sand material to soft soil raises the volume weight of soil mixed with sand by an average of 5.94%, while the cohesion value of soft soil mixed with sand decreases by an average of 25.07% when compared to pure clay soil.

3. Theoretical basis

Soil is a material composed of solid mineral grains that are not chemically bonded to one another, as well as decomposed organic matter, with liquids and gases filling the spaces between the solid particles (Das, 1988). Furthermore, the soil is an aggregation of mineral particles or connections between particles created as a result of rock weathering (Craig, 1991).

Organic soil is soil that contains a high concentration of organic components and has a thickness ranging from several meters to tens of meters underground. Organic soils are dark in color and make up the majority of peatlands. This sort of soil is prone to large settlements in general.

Table 1. (Planning of construction of road embankments on peat with the preloading method, 2004)

Soil Type	Organic Level (%)
Clay	<25
Organic Clay	25-27
Peat	>75

Permeability is a measure of the ease with which fluid flows through porous media. The permeability coefficient is the only quantitative measure of permeability. Soil texture, organic matter, bulk density, particle density, soil porosity, and effective soil depth are all characteristics that influence permeability (Hanafiah, 2005).

Flow properties in the soil can be laminar or turbulent. Flow resistance is affected by soil type, particle size, grain shape, mass density, and the geometry of the pore cavity.

Table 2. Variation of $\eta_{T^\circ C}/\eta_{20^\circ C}$ value

Temperature, T (°C)	$\eta_{T^\circ C}/\eta_{20^\circ C}$	Temperature, T (°C)	$\eta_{T^\circ C}/\eta_{20^\circ C}$
15	1.135	23	0.931
16	1.106	24	0.910
17	1.077	25	0.889
18	1.051	26	0.869
19	1.025	27	0.850
20	1.000	28	0.832
21	0.976	29	0.814
22	0.953	30	0.797

Table 3. Soil permeability rate classes

Soil permeability classes	Permeability rates[1]	
	cm/hour	cm/day
Very slow	Less than 0.13	Less than 3
Slow	0.13 - 0.3	3 - 12
Moderately slow	0.5 - 2.0	12 - 48
Moderate	2.0 - 6.3	48 - 151
Moderately rapid	6.3 - 12.7	151 - 305
Rapid	12.7 - 25	305 - 600
Very rapid	More than 25	More than 600

Bio-grouting is a novel environmentally friendly stabilization process that uses microorganisms to stabilize fragile soils. CaCO3 is produced by microorganisms and fills holes in soil particles, binding them together. The bacteria *Bacillus subtilis* was used in this study to investigate the bio-grouting of high-plasticity tropical organic soils.

Bacillus is a gram-positive rod-shaped bacteria that grow best at temperatures ranging from 25 to 35°C. Although Bacillus is considered to be completely aerobic, it was later revealed that under certain conditions, it may live anaerobically. Bacillus is found naturally in soil, where it colonizes root systems and competes with other bacteria such as fungi. *Bacillus subtilis* is safe when used as a probiotic and as a food component. Bacillus can develop stress-resistant endospores as a defense mechanism in extreme environments. Spores are resistant to heat, radiation, and chemicals, as well as desiccation.

4. Research method

Location, tools, materials, research stages, and procedures for preliminary and major testing are all part of the research method. The physical properties of peat soil were tested as part of the preliminary testing in this study, and the main test was the permeability of peat soil added to the sand mixture and the application of bio-grouting utilizing the *bacillus subtilis* bacteria.

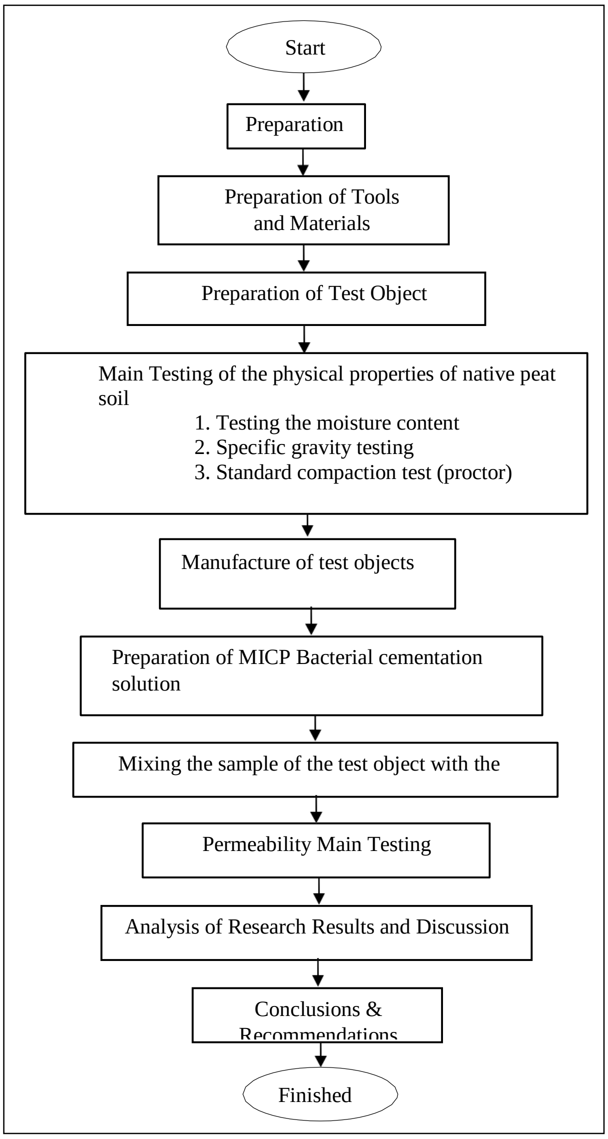

Fig 1. Research Flowchart

This cementation solution is a mixed solution of Urea and CaCl2 which is used by bacteria to produce CaCo3 (Calcium Carbonate).

For the manufacture of cementation solution, the tools and materials must be prepared. These tools consist of cups, spoons, digital scales, aqua bottle containers, pycnometer tubes, measuring cups, funnels, and filter paper. Meanwhile, the ingredients are bacteria, CaCl2, urea, and water.

Table 4. Materials mixed cementation solution

No	Material	Total
1	Bacteria	10 ml
2	Urea	1000 gr
3	Cacl2	10 gr
4	Water	50 ml

5. Results and Discussion

5.1. Original soil water content

This water content test was performed following the ASTM D2216-98 method. The results of the water content tests on the test soil yielded a water content value of 407.5%. This is because the original soil examined contains organic fiber content (peat), which may absorb a lot of water and so has a high water content. Peat has a water content ranging from 200% to 900%, according to the Transportation Infrastructure Research and Development Center. A water content testing table is shown below.

Table 5. Data for water content testing (ASTM D2216-98)

LETTER	DESCRIPTION	UNIT	M7	M21
A	Cup Weight	gr	63.2	62.7
B	Cup Weight + Wet Soil	gr	167.1	155.9
C	Cup Weight + Dry Soil	gr	84.1	80.7
D	Water Weight (B-C)	gr	83	75.2
E	Dry Soil Weight (C-A)	gr	20.9	18
F	WATER CONTENT (D/E X 100%)	%	397.129	417.778
G	Average Water Content			407.4534822

5.2. Specific Weight

ASTM D 854-02 was used to conduct this Specific Gravity Test. According to the results of the tests performed on the original soil, the specific weight (Gs) value of the soil utilized is 0.544. The presence of wood fibers and other organic content in peat soils contributes to the specific weight value (Gs). A specific gravity test table is provided below

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For the manufacture of cementation solution, the tools and materials must be prepared. These tools consist of cups, spoons, digital scales, aqua bottle containers, pycnometer tubes, measuring cups, funnels, and filter paper. Meanwhile, the ingredients are bacteria, CaCl2, urea, and water.

Table 6. Specific gravity test (ASTM D 854-02)

1	Picnometer No.	A9
2	Mass of pycnometer M_1 gram	70.7
3	Mass of dry soil + pycnometer M_2 gram	78
4	Mass of dry soil + water + pycnometer M_3 gram	169
5	Mass of water + pycnometer M_4 gram	167.3
6	Temperature t°C	
7	$A = M_2 - M_1$	7.3
8	$B = M_3 - M_4$	1.7
9	C = A - B	5.6
10	Specific Gravity, $G_1 = A / C$	1.30

5.3 Compaction Test

Compaction testing was carried out to obtain a maximum dry unit weight (γd max) value of 0.467 gr/cm^3 of the original soil and an optimum moisture content (OMC) of 157% of pure soil.

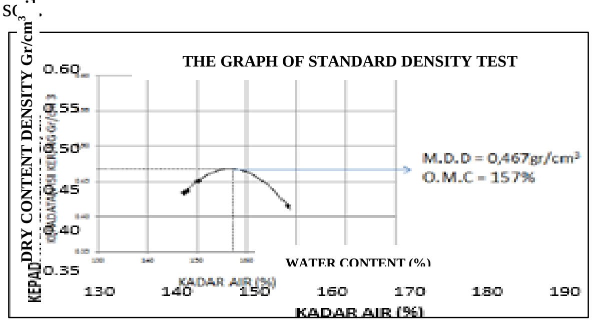

Fig 2. Correlation between dry volume weight and moisture content

The high value of the optimum moisture content (OMC) is caused by the large pores of the soil which consist of plant (organic) fibers, causing the soil to absorb a lot of water to achieve optimum density. The optimum moisture content (OMC) obtained from the compaction test on the original soil is used as a comparison to the soil conditions used in the modeling test. According to the dry unit weight obtained, the peat classification is based on the dry unit weight at the level of weathering or decomposition > 0.2 gr/cm^3 (Mutalib, et al., 1991). Peat soil originating from Siak is categorized as sapric peat because it is formed due to the influence of soil minerals.

5.4 Characteristics of Peat Soil

The results of the tests provide a summary of the physical properties of the soil. The physical properties of peat soil determined from preliminary testing are shown in the table below.

Table 7. Peat Soil Properties

NO	Traits	Size	Unit
1	Specific Weight, *Gs*	1,3	-
2	Water Content, *w*	407,5	%
3	Maximum dry content weight (γd maks)	0,467	Gr/cm^3
4	Optimum water content (OMC)	157	%

5.5 Peat Soil Permeability Test using a Mixture of Sand and *Bacillus subtilis* Bacteria

The falling head method was utilized in this permeability test, which involved combining *bacillus subtilis* bacteria in a solution (cementation solution) with peat soil mixed with sand. Sand makes up to 5% of the weight of the peat soil sample in the specimen sample. The samples to be examined were soil samples without mixture, soil samples with 5% sand mixture, and soil samples with 5% sand mixture and 25% bacterial cementation solution that had been previously saturated before testing. The purpose of saturating the sample is to remove the sample's air pores.

Table 8. Data on the amount of water per 2 minutes at the start of the sample without any mixture

NO	Time (minutes)	Amount of escaped water (ml)
1	2	1,8
2	2	4,8
3	2	2
4	2	3,2
5	2	3,2

Table 8 data shows that the sample without mixing within 10 minutes was able to drain 15 ml of water. Thus, to reach peak dripping, the sample without mixture takes 23 hours and 50 minutes.

After the test is completed, the amount of water per 2 minutes at the start of each sample was obtained, and the duration of time for the water to drip. The data on the amount of water every 2 minutes at the start of each sample is presented in the table 8.

Table 9. Data on the amount of water per 2 minutes at the start of the sand-mixed sample

NO	Time (minute)	Number of escaped water (ml)
1	2	3,6
2	2	3,4
3	2	3,4
4	2	3,1
5	2	2,9

The data in Table 9 shows that the sample with a mixture of sand within 10 minutes was able to drain 16.4 ml of water. Thus, it took 23 hours and 5 minutes to reach peak dripping for this sample.

Table 10. Data on the amount of water per 2 minutes at the start of the sample of a mixture of sand and 25% bacteria

NO	Time (minute)	Number of escaped water (ml)
1	2	18
2	2	6
3	2	4,2
4	2	3,8
5	2	3,8

Based on the data presented in Table 10, samples with a mixture of sand and 25% bacteria were able to drain 35.8 ml of water in 10 minutes. To reach the peak dripping, this sample took 20 hours and 53 minutes.

The data presented in the table above show that the sample without the mixture differs from the sample with the sand mixture as well as the sample with the sand mixture and 25% bacteria. In this case, the amount of water per 2 minutes without a mixture has a surface dripping time duration of 23 hours 50 minutes, a sand mixture has a surface dripping time duration of 23 hours 5 minutes, and a sand and 25% bacteria mixture has a surface dripping time duration of 20 hours 53 minutes. The difference in the amount of water that escapes in the first 2 minutes for each sample is presented in the following graphic.

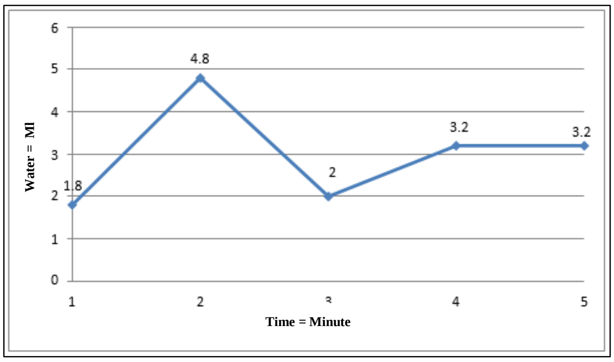

Fig 3. Original soil in dripping water every 2 minutes at the start

In the graphic image above, it can be seen that in the first 2 minutes, the original soil sample drained 1.8 ml of water. In each of the following 2 minutes, the amount of water dripped is 4.8 ml, 2 ml, 3.2 ml, and 3.2 ml, respectively.

In the graphic image above, it is shown that in the first 2 minutes, a soil sample with a 5% sand mixture was able to drip 3.6 ml of water. In each of the following 2 minutes, this sample released 3.4 ml, 3.4 ml, 3.1 ml, and 2.9 ml of water, respectively.

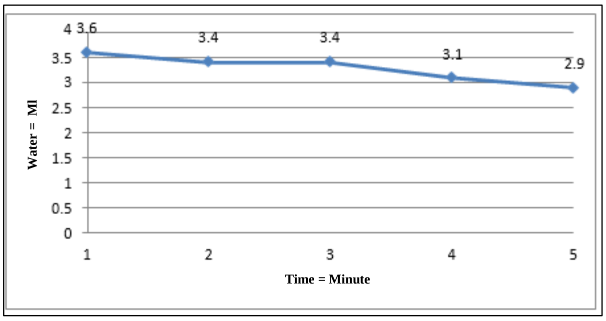

Fig 4. Soil with a mixture of sand 5% in dripping water every 2 minutes at the start

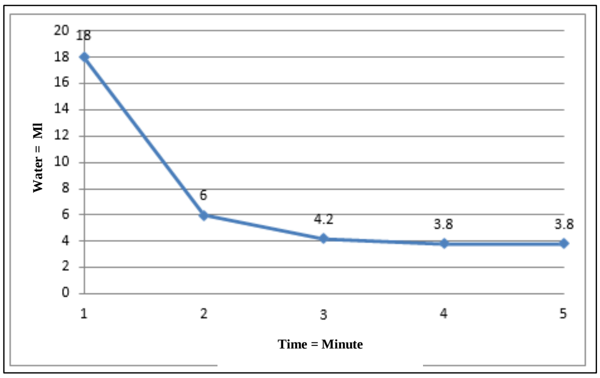

Fig 5. Soil with a mixture of 5% sand and 25% bacteria in dripping water every 2 minutes at the start

In the graphic image above, it is shown that in the first 2 minutes, a soil sample with a mixture of 5% sand and 25% bacteria was able to drain 18ml of water. For each of the next 2 minutes, the amount of water flowing is 6ml, 4.2ml, 3.8ml, and 3.8ml respectively.

Table 11. Coefficient of permeability of 26^{o}C water temperature test samples

NO	Sample	Permeability speed (cm/second)
1	Oginigal soil	1,126x10^{-3}
2	Soil Mixed With Sand	1,108x10^{-3}
3	Soil mixed with sand and 25% bakteria	1,342x10^{-3}

In Table 11, the permeability rate values of each sample tested using the falling head test equipment are presented. In the original soil sample, the permeability rate is 1.126x10^{-3}cm/second. The permeability rates of the sand-mixed soil sample and the sand-mixed soil sample and 25% bacteria were 1.108x10^{-3}cm/second and 1.342x10-3cm/second, respectively.

The following is a graphic image for the 26^{o}C water temperature permeability test.

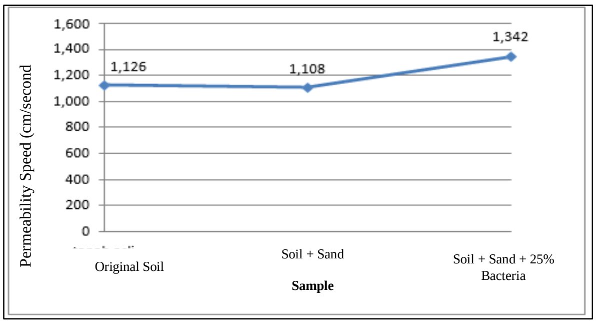

Fig 6. Graphic of 26^{o}C water temperature permeability coefficient

The results of Figure 6 on the graph, the permeability value with a mixture of sand and 25% bacteria and a water temperature of 26ºC experienced a permeability rate increase of 1.342x10^{-3}cm/second. Furthermore, in the original soil sample, the permeability rate was 1.126x10^{-3}cm/second, while the sample with the addition of sand decreased, namely with a speed of 1.108x10^{-3}cm/second.

Table 12. Permeability coefficient with standard water temperature testing of 20ºC

NO	Sample	Permeability Speed (cm/second)
1	Original Soil	9,784x10^{-4}
2	Soil mixed with sand	9,624x10^{-4}
3	Soil mixed with sand and 25% bacteria	1,166x10^{-3}

The permeability coefficient after being determined with the standard 20ºC water test on the test is shown in Table 12.

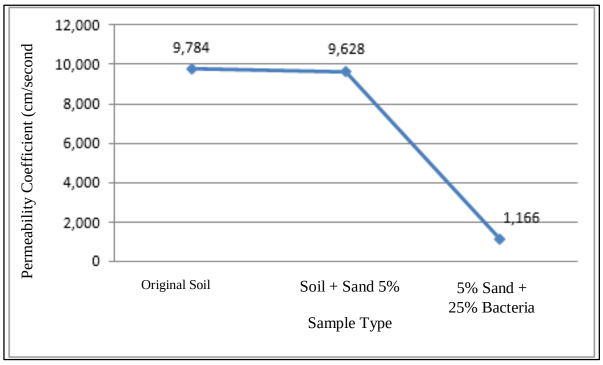

Fig 7. Graph of the permeability coefficient of 20ºC water temperature

There is a difference in the permeability coefficient of the main test before using the standard water temperature test with temperature 26ºC and after testing standard water temperature 20ºC.

Table 13. Comparison of the water temperature coefficient of 26ºC and 20ºC

NO	Sample	Permeability coefficient cm/second	
		26ºc	20ºc
1	No mix	1.126	9.784
2	5% sand mixture	1.108	9.628
3	5% sand and 25% bakteria	1.342	1.166

In Table 13, the difference in the permeability coefficient before and after it is calculated with a standard water temperature of 20ºC is presented.

The following are some comparisons of permeability tests that can be used as a comparison in this test.

Table 14. Comparison of the permeability coefficient of the main test with the slag/clinker mixture

NO	Main Test	terak/klinker	Coefficient of Permeability Value cm/second	
			Main Test	terak/klinker
1	No Mix	0%	1.126	4.53
2	5% sand mixture	4%	1.108	4.03
3	5% sand and 25% bacteria	8%	1.342	2.97

6. Conclusion

Peat soil mixed with sand and 25% bacteria experienced an increase in permeability compared to the original soil sample and mixed sand soil with a permeability coefficient of 1.342x10^{-3}cm/second. In the original soil sample, the permeability coefficient was 1.126x10^{-3}cm/second, while in the sand-mixed soil sample, the permeability coefficient was 1.108x10^{-3}cm/second.

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