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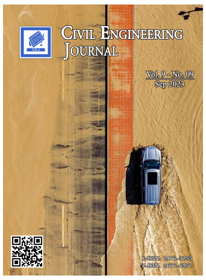

Characteristic and Physicochemical Properties of Peat Soil Stabilized with Sodium Hydroxide (NaOH)

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Abstract

Peat in various phases of decomposition has poor shear strength and high compressive deformation. For this research study, it will focus on stabilizing peat soil using NaOH. There are two main tests that were conducted in this research study, which are index property testing and the compaction test. For index property testing, there were six (6) experiments conducted to study the index properties of disturbed peat soil, which are moisture content, fiber content, organic content, liquid limit, pH, and specific gravity. Then, for the compaction test, a 4.5kg rammer was used to determine the best mixture of stabilizer blended with different volumes of 5%, 7%, and 9% stabilizer. The desired outcome of this study is to stimulate further research into the use of the chemical NaOH as a peat soil stabilizer for improved soil usage. 7% and 9% of NaOH only have a slightly different percentage, and it can be concluded that this was the optimum percentage of NaOH as a chemical stabilizer for peat soil. It can be seen clearly that 5% is the higher dry density with a lesser moisture content of the peat. When the percentage of NaOH was increased, the graph pattern also changed. NaOH has been observed as an alteration agent for peat soil dry density. It can be seen clearly that 5% NaOH is the higher dry density of the peat with the lesser moisture content and is suitable as a peat soil stabilizer. The increment of oxygen content recorded changes from 13.3% to 23%, while the sodium (Na) content decreased significantly with the increment of oxygen (O). Sodium content decreased from 8.7% for untreated specimens to 4.5% and 5.5% when peat was treated with NaOH, with 5% of NaOH and 9% of NaOH.

Keywords: Peat; Stabilization; Sodium Hydroxide; Dry Density; Physicochemical.

1. Introduction

The organic surface layer of a soil is characterized as moderately degraded organic matter, mostly derived from plant material that has developed under conditions of waterlogging, oxygen deprivation, high acidity, and nutrient depletion. As claimed [1], individual peat particles are compressible, which allows them to defy another fundamental principle in soil mechanics. Peat soils are the most common type of organic soil, formed over generations by the accumulation of partially digested and undecomposed plant wastes under wetland conditions [2]. The other type of organic soil is muck, which is formed by the accumulation of organic soil elements. However, the components in this type are pretty thoroughly decomposed, and the sources of the materials are unknown. Saturation or submergence of the substratum, along with the complete lack of free oxygen, results in a very slow anaerobic breakdown of organic materials, allowing the evolution of deep organic soils called *Histosols*.

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A peatland, on the other hand, is a large area of peat soil. Peatlands make up more than half of the world's wetlands, accounting for 3% of the planet's land and freshwater surface. Wetland types that produce peat soils include mires (bogs, fens), swamps, and marshes. Peat soils may be found in all climates, although they are more common in the Northern Hemisphere's temperate and cold zones. Individual peat particles are compressible, which allows them to defy another fundamental principle in soil mechanics. High water table, lack of oxygen, decreasing condition, poor bulk density and bearing capacity, soft, spongy substratum, low fertility, and frequently high acidity define peat soils.

Malaysia has over 2.5 million hectares of peat soil, with Sabah accounting for roughly 4.76% of the country's peat soil area. Sarawak has the biggest peat soil in Malaysia, covering 1.66 million acres, or 13% of the state's total area [3]. There are two surviving places in Sabah that support the biggest expanses of peat soil: the Klias Peninsula and the Kinabatangan-Segama Valleys. From an engineering standpoint, the Sabah peat soil data project was developed in 2016. The carrying capacity of peat soil was shown to be relatively low in studies done by Andriesse [4] and Hashim & Islam [5]. It was presumably impacted by the water table and the presence of underlying woody debris. Unexpectedly, when treated to a low weight, peat creates major issues in the building sector because of its long-term consolidation settlements. As a result, peat in its natural condition is regarded as inappropriate for sustaining foundations. Conducted a test on peatland in Peninsular Malaysia and discovered that the peat had a very high water holding capacity, was dark brown in color, and was categorized H4 by the Von Post classification system [6].

Peat is a problematic or weak soil made up of decomposed organic matter. Low shear strength (3–16 kPa), high water holding capacity (up to 850%), high compressibility with an initial void ratio in the range of 5–15, and the possibility of degrading further over time make peat unsuitable for the foundation. As a result, stabilization is an unavoidable part of any infrastructure development in peat. Soil stabilization is the mechanical or chemical modification of one or more soil qualities to produce a better soil material with the necessary engineering properties [2]. In this further research, the chemical stabilizer used is sodium hydroxide (NaOH). The goal of this study is to use NaOH as a stabilizing agent to chemically stabilize the soil. Sodium hydroxide is a non-combustible, odorless, white flake solution that does not burn but is very reactive. NaOH decomposes into (Na+ and OH-) ions, which interact with soil minerals to modify their characteristics. For building and construction needs, soil from Ghana was stabilized by combining and curing it with various chemicals. These additives have the best failure resistance in the dry state, but NaOH has the best failure resistance in the wet condition. The decrease in liquid limit with increasing NaOH concentration was also discovered to be attributable to the major influence of increased electrolyte concentration [7].

A laboratory compacting process for determining the optimal water content at which a soil can be compacted for maximum density (dry unit weight). The approach is inserting a soil sample with a known water content in a mold with specific dimensions, subjecting it to a controlled compactification effort, and calculating the resulting unit weight (ASCE, 1958, term 74). The method is repeated for a variety of water contents until a relationship between water content and unit weight is established. The maximum dry density for a given compactification effort will usually result in a sample with near-maximal saturated strength. The type of compaction and the amount of energy provided for a given soil volume are both standard; thus, the test focuses on changing the moisture level of a sample to determine the optimum water content. A 0.95-liter cylindrical mold is used in the typical test, in which the soil mass is put in and compacted in three layers.

Peat in various phases of decomposition has poor shear strength and a high compressive deformation, which causes problems when construction work is done on the deposit [8]. Organic soil is defined as soil that contains more than 20% organic matter. Deep peat has problems because of its physical and chemical qualities. Peat absorbs an excessive amount of water in its natural condition due to its low physiography and water retention potential of 20 to 30 times its own weight. As a result, aeration is poor and bulk density is low, at less than 0.1 g cm^{-3}. When peat is drained, it will dry irreversibly and subside at a rate of 3.6 cm per year. Peat has traditionally been thought of as a material with high compressibility and low bearing capacity, according to previous research. Prior to the study of Mohamad et al. [9], most engineers have been concerned about peat's reactions to roads and highways in Malaysia since peat soil is defined as "poorly, challenging, difficult accessibility, and problematic soil." Peat soil is a troublesome soil, and every engineer has sought to avoid working with it. When the major reason is peat soil, a variety of issues might arise, including slip failure, local sinking, and long-term settling as the load increases. This problem appears to be best solved by stabilizing. To improve the shear strength of peat soil, using a chemical stabilizer, which is NaOH, is a suitable way to increase the quality of peat soil. The compaction test is the best method to improve soft soil shear strength, slope, and embankment stability and is especially useful for soils with low hydraulic conductivity.

The goal of this research is to anticipate the ability of sodium hydroxide (NaOH) as a chemical addition in peat soil stabilization under compaction compression conditions, as well as the impacts of the approaches. However, the study's more precise objectives had to be achieved, including studying the index properties of peat soil and the behavior of

NaOH in peat soil under compaction conditions. Equally important is determining the dry density and moisture content of peat soil after it has stabilized. The compaction method is employed as a mechanical method in conventionally mixed peat with a chemical stabilizer for peat soil to determine the combination effect of NaOH on peat soil.

1.1. Sodium Hydroxide (NaOH)

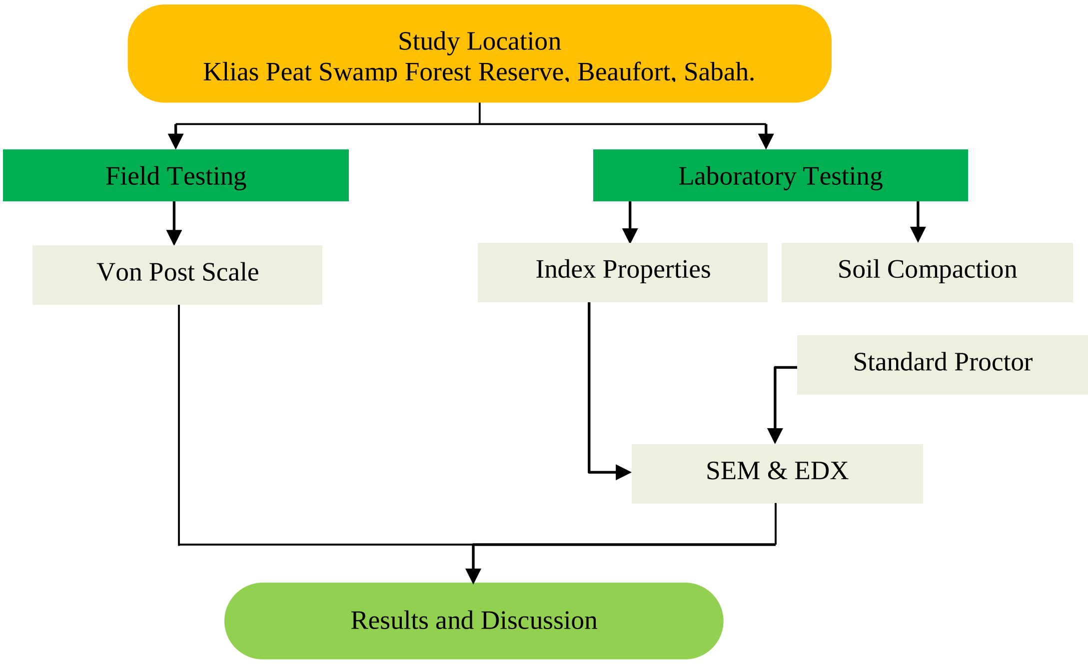
The purpose of this study is to enlighten and dive deeper into the use of NaOH as a chemical stabilizer for peat soil stabilization using compaction testing in order to get the best out of the problematic soils. The goal of this study is to fill in the gaps in the understanding of peat soil behavior with a specific stabilizer concentration and compaction test to improve shear strength. To date, no one has looked at the relationship between NaOH and the compaction test in order to develop the qualities of soft soils. This technology will aid engineers in understanding peat soil issues while also establishing a new strategy in the market.

Sodium hydroxide is a colorless, odorless, and non-volatile solution that is extremely reactive. It has the ability to create enough heat to ignite flammable materials nearby, as well as react severely with water and other elements encountered. The major benefit of sodium hydroxide is that it can help with compaction by increasing density. When reacting with water, the same compactive effort is required [10]. To test the effect of altering sodium hydroxide concentration, sodium hydroxide pellets were added to water, and various percentages ranging from 7% to 16% were utilized in the soil sample while retaining other ingredients: 100% filler (sand), 18% water, and 100% clay were kept. 13% sodium hydroxide, 18% water, and 100% clay soil were held constant to observe the effect of changing filler percentages ranging from 50% to 200%. The NaOH solution was made by dissolving NaOH pellets in water and then adding them to the clay-sand combination.

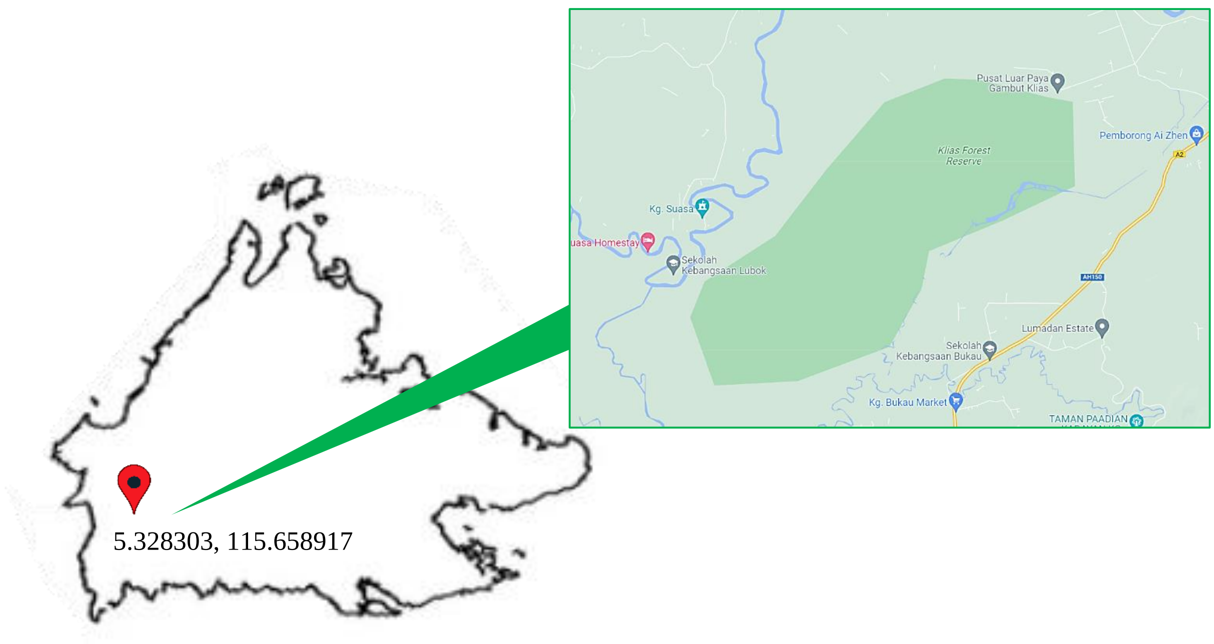
Increasing the clay-to-sand ratio or using a smaller quantity of filler increases kaolin activity. As a result, the mineral polymerization process was accelerated [11]. Because harder geopolymeric products are formed by increasing kaolin activity, the strength rises. At the greatest clay-to-sand ratio, the compressive strength was the highest. Dried specimens had the highest compressive strength of all the specimens, whereas moist specimens had the lowest. Sodium hydroxide may modify the clay mineral lattice by alkaline assault, resulting in a significant link between compressive strength and sodium hydroxide concentration. Sodium hydroxide is used as a chemical additive because it acts as an excellent compaction aid between soil particles and is extremely water-soluble. For different concentrations of NaOH by weight of soil and the change of water content vs. dry density, it can be seen that the maximum dry density of soil increases with concentrations of 4M, 6M, and 10M [12]. This suggests that there is an optimal moisture content at a 6M concentration that improves the qualities of the soil and allows it to be utilized in the field. When the concentration of NaOH is increased, the optimal moisture content and dry density drop. It may be said that a concentration of 6M is adaptive [12]. NaOH pH value is 13, where it is classified as alkaline [12], and peat is acidic with a pH value of 4.0 [13]. Peat is in the category of problematic soil because it has low shear strength and high compressibility [9, 14]. It was also discovered that increasing the cement dosage and extending the curing period resulted in treated peat soil with higher strength for all types of peat. While the improvements identified in the phase of a crystalline material between peat and EPP and cement in peat soil [15].

2. Materials and Method

This analysis is meant to work out the effect of sodium hydroxide (NaOH) as a chemical stabilizer for peat soil. In accordance with BS1377:1990 [16], British standard research methods for soil civil engineering purposes have been applied, the connected laboratory work and tests have been applied, and every one of the necessary elements of this analysis has been given intimately to determine the results of the study. This research was carried out with the goal of determining the hardening effects of NaOH on peat soil as a therapeutic approach for problematic soil. The role of this chemical component in the soil stabilization process was determined using a descriptive research approach. The first test is the index properties test. These tests are designed to assess the soil attributes based on a number of factors. Moisture content, pH, specific gravity, fiber content, organic content, and liquid limit are among the six tests specified for index properties. All six have been carried out using BS1377:1990 as a reference. The compaction test was the next test. The Standard Proctor Compactor is the type of compaction test that will be used. The goal of the test is to determine the highest dry density that may be achieved for a specific soil with a reasonable amount of compaction effort. All of the tests have been carried out on the same sample, which was peat soil from Klias, Beaufort, and Sabah. The goal of this laboratory examination to be performed on peat soil is to examine the soil properties and the reaction of peat soil with NaOH. This approach was illustrated from the beginning to lead to Figure 1.



(a) Flowchart of Research



(b) Location of Klias Peat Swamp Forest Reserve, Sabah, Malaysia

Figure 1. Research area and process

Beaufort, Sabah, who is stressing the significance of peat deposit peat at Klias, recently conducted an engineering study on peat soil in Sabah. This place is well established as a peat deposit area, based on some of Sabah's difficult zones dealing with peat soil. This research has been carried out in the Beaufort region of Sabah, Malaysia's southern state, where there is a large wetland area. This swampy lowland plain is known as the Klias Peninsula. Beaufort has a total area of 466,804 hectares. This area receives between 2,500 and 3,000 mm of yearly precipitation. The rest of the Klias Peninsula is covered in wetlands and serves as a 'buffer zone' to the 'core.' Between Kimanis Bay to the north and Brunei Bay to the south, it faces the South China Sea and is encompassed by the administrative borders of both the Beaufort and Kuala Penyu Districts.

The region is frequently referred to as a forest reserve (red boundaries indicate forest reserves in figure 3.2). Some consider the area between 115.45' and 115.72'N and 5.42' and 5.15'E to be a completely covered peat swamp forest (Class 1). Class 1 Forest Reserves are extremely well-protected areas, with 342216 hectares total. Class 1 forests are protected largely for environmental reasons and to preserve biodiversity. They are legally protected against land modification and wood extraction. This study was conducted based on research carried out on peat soil compaction characteristics and physicochemical changes treated with Eco-Processed Pozzolan (EPP) [17].

Disturbed soil samples do not retain the in-situ features of the soil during the collecting procedure. Testing for disturbed soil samples is often used to analyze soil type and texture, moisture content, and nutrient and contaminant analyses, among other things. Clearing and grubbing are done at the same time to prepare the site for the sample. After clearing and grubbing, excavation operations began immediately to equally collect topsoil from where the ground water table was less than 0.5 meters below ground level and up to a depth of 0.5 m below ground level. Disturbed soil samples are collected with a tiny shovel. As a backup storage medium, large samples of excavated peat soil will be stored in heavy-duty plastic bags. The disrupted sample was placed in a plastic bag in a heavy-duty container 64 and transported to the laboratory, where it was stored at room temperature to retain moisture. Visual examination of the peat soil is carried out after the collection of disturbed samples, as indicated in the Von Post categorization system. The sample consistency of this type of undisturbed sample would be at most unaltered under BS 5930:1999, the code of practice for site investigations. The index properties of peat soil, pH value, moisture content, liquid limit, density, specific gravity, organic content, and fiber content are analyzed. Compaction has been used to compare the characteristics of peat soil before and after treatment. The peat soil sample came from Klias in Beaufort. A 0.95-liter volume cylindrical mold is used in the typical Proctor test, in which the soil mass is put in and compacted in three layers. Each layer is compacted by dropping a 2.5 kg weight from a height of 30 centimeters 25 times.

The Von Post scale is easy to use; simply squeeze a little amount of moist soil (enough to be covered by the fingers of one hand) as shown in Figure 2, until as much as possible has come through the fingers. Small enough to fit between the palms of one hand, the moist earth is squeezed firmly between them until as much of it as possible protrudes through. Additionally, it is noted that the exudate's color and viscosity, as well as the proportion and position of the final fiber and other characteristics, are present. From the result of the test at the site, it can be justified that the class of humification of peat soil at Klias, Beaufort, is H5, where the peat is dark brown, turbid water with no organic solids squeezed out. It only released very muddy water with a very large amount of amorphous granules that escaped between the fingers.

(a) Peat squeezed on palm (b) Peat remaining

Figure 2. Von Post's Test at The Klias, Beaufort

In the course of the peat soil compaction test, the sample used was disturbed and sieved on a 200-mm sieve plate. Throughout the experiment, data such as moisture content, bulk density, and dry density were recorded as parameters of finding. There are four samples being tested. Each sample has a weight of 2000g of peat soil. The method used is a 4.5-kg rammer. Tested samples were tagged as Mix 1, Mix 2, Mix 3, and Mix 4. Mix 1 is the controlled sample, peat soil, without any addition of stabilizer, being NaOH. Mix 2 is peat soil with the addition of NaOH at 5% of the weight of peat soil. Mix 3 differs from Mix 4 in the concentration of stabilizer. Mix 3 is peat soil coupled with an equal concentration of NaOH, which is 7%, respectively, from the weight of peat soil used, whereas Mix 4 is peat soil combined with 9% NaOH.

The NaOH comes in powder form. Subsequently, NaOH was weighed to a specific weight of 100g, 140g, and 180g, respectively, and then mixed in 50ml of distilled water. For Mix 2, NaOH is added to 50 ml of distilled water, and then it is cured for 1 hour. For Mix 3 and Mix 4, NaOH of specific weight is added to distilled water with an additional 4% from the 50-ml water and cured for 1 hour. The samples are then allowed to absorb the stabilizer and water after 1 hour of curing. So, the purpose of 1 hour of curing is to ensure the chemical can fully react with the peat soil and also for safety. Due to the characteristics of NaOH itself, which are highly reactive and have enough heat to ignite combustive materials nearby, after 1 hour of curing, the temperature of the mixed peat soil will be reduced and safe to use. Table 1 shows the ratio design of peat and NaOH.

Table 1. Mix proportion of peat and NaOH ratio

Description	Mix 1	Mix 2	Mix 3	Mix 4
Specimens	Peat soil	Peat Soil with 5% of NaOH	Peat Soil with 7% of NaOH	Peat Soil with 9% of NaOH
Curing time	-	1 hour	1 hour	1 hour
Mixture	150 ml of distilled water	100g of NaOH 50 ml of distilled water	140g of NaOH 52 ml of distilled water	180g of NaOH 54 ml of distilled water

3. Results and Discussion

Moisture content on peatland in Peninsular, Malaysia and found that the water holding capacity of this peat was very high, it was dark brown in color, and the soil was classified H4 according to the Von Post classification system. The water content of peat researched in West Malaysia ranges from 200% to 700%. According to Zainorabidin & Mohamad [18], Sabah has the highest water content in peat, which can roughly reach 1000%. Natural moisture content is determined using the oven dry method, which involves heating the item in the oven for 24 hours at a temperature of 150°C. Four plates of samples were prepared for testing, and the average moisture was taken from them. In this study, the average moisture content of peat soil was determined to be 550%. According to Mesri & Ajlouni [19], peat moisture content can range from 200% to 2000%, which is significantly higher than clay and silt deposits, which seldom surpass 200%. According to Mohamad et al. [13], varying numbers of moisture content have been observed in previous studies on moisture content, ranging from 491.16% to 985.3% and 546.43%, according to bin Zainorabidin et al. [20]. When the ground temperature is lower, the quantity of water content increases, and shear strength drops; when the ground temperature is higher, the quantity of water content reduces, and shear strength increases. These discrepancies in results, according to Mohamad et al. [13], are due to climate change as a result of changes in temperature, precipitation, and rainfall influencing soil saturation intensity, in which the water table forms in a horizontal plane and may emerge at a level greater or less than the actual water table.

The average pH value for peat soil was determined to be 2.3 on the acidic scale. Mohamad et al. [13] discovered that peat acidity ranges from 4.0 to 4.9; Sutejo et al. [21] discovered that peat pH ranges from 3.16 to 3.71; and bin Zainorabidin et al. [20] discovered that peat pH ranges from 3.3 to 3.9 on the acidic scale. The acidity of tropical peat soils, according to Dariah et al. [22], ranges from 3 to 5. As a result, this result is deemed sufficient since it falls within the range of previous researchers' findings. The rate of organic material breakdown (decay) and the depth of peat impact soil pH variability. The average specific gravity is 1.47. Hauashdh et al. [23] discovered that the specific gravity of peat soil at Kampung Medan Sari, Johor, is 1.63. According to Zolkefle [24], the specific gravity of peat soil is 1.34. Although it may be linked to the mineral composition and weathering of peat soil, specific gravity is an important parameter in peat soil mechanics. From the laboratory testing of organic content, the average loss of ignition is 96%. It can be calculated by the weight of the sample before heating minus the weight after heating, which is the "initial" loss on ignition. Then, to determine the percentage of loss on ignition, divide "initial loss" by the initial weight of the sample and multiply by 100. According to Mohamad et al. [13], the organic content of peat soil is between 53.97%–95.51%. Soil scientists define peat as organic soil with an organic content greater than 35%. To a geotechnical engineer, however, all soils with an organic content of greater than 20% are known as organic soil, while "peat" is an organic soil with an organic content of more than 75% [25]. In this study, the result of the fiber content test was 75.92%, which can be classified as fibrous peat. Fibrous peat soil is known for its high fiber content (FC) and organic content (OC). The characteristics of peat land with fibrous peat soil are not the same as those of clay soil because of the different soil properties and structures. According to the previous researchers, according to Mohamad et al. [13], the fiber content of peat is 61.61%–79.40%. For other researchers, the fiber content of peat soil is 70.45%–76.659% [21]. Table 2 shows the index properties of peat soil in Klias, Sabah.

Table 2. Index properties of Klias peat soil

Properties	Value
Natural Moisture Content, w (%)	510
Specific Gravity (Gs)	1.23
Liquid limit, %	182
Acidity (pH)	2.12
Organic Content (%)	91
Degree of humification	H5
Fiber Content (%)	75.92

Figure 3 shows the dry density versus moisture content of untreated peat soil treated with NaOH. Fortunately, for the peat soil that is not stabilized (untreated), the dry density is seen to be high at 0.58 after adding the last 4% of water with a moisture content of 55%. The best fit line that expressed the relationship between those points was the lowest, which is 0.11. Unfortunately, for the treated sample, which contains 5% NaOH (Mix 2), it is clearly seen that the highest dry density is at 0.54 with a moisture content of 65%. There is just a slight difference with the untreated peat, with a 10% difference. The best fit line that expressed the relationship between those points was 0.255. Consequently, in Mix 3, the dry density was almost equal to that of the untreated peat, which was 0.45 with a moisture content of 106%. In the event that there are changes in the graph pattern, for Mix 4, which is 9% NaOH, the highest dry density is 0.45 with a moisture content of 124%. The best fit line that expresses the relationship between those points is 0.1364. From the result table and the graph pattern, 7% and 9% of NaOH only have slightly different values, and it can be concluded that this was the optimum percentage of NaOH as a chemical stabilizer for peat soil. This is because, for the percentage 5% of NaOH, there was no clear difference between the treated and untreated samples of peat soil. When the percentage of NaOH was increased, the graph pattern also changed. From the trend of the graph, it can be concluded that from 0% of NaOH until 9% of NaOH, the linear line from the graph is gradually decreasing. It can be seen clearly that 5% NaOH is the higher dry density of the peat with a lesser moisture content and is suitable as a peat soil stabilizer.

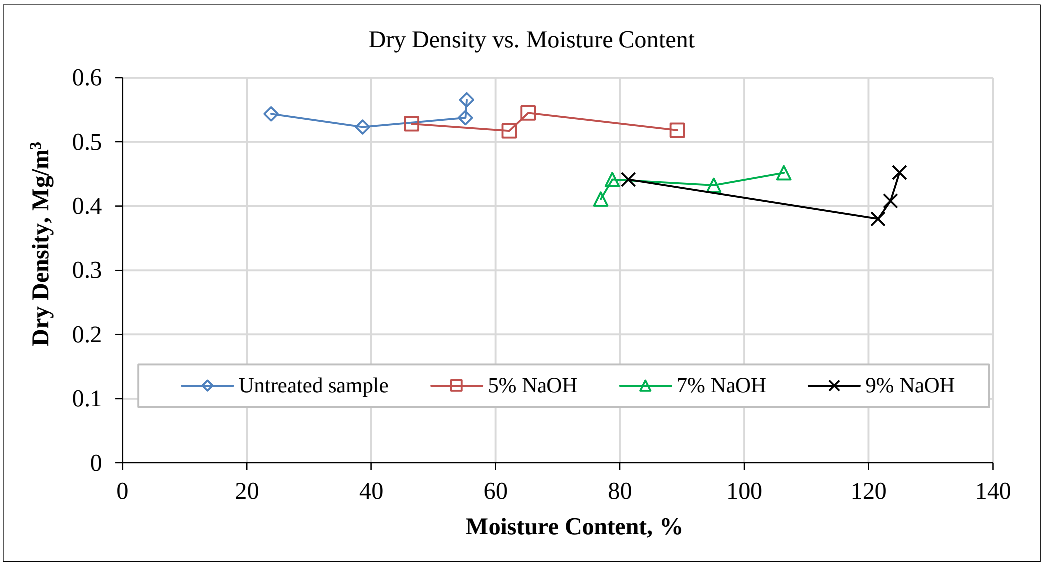
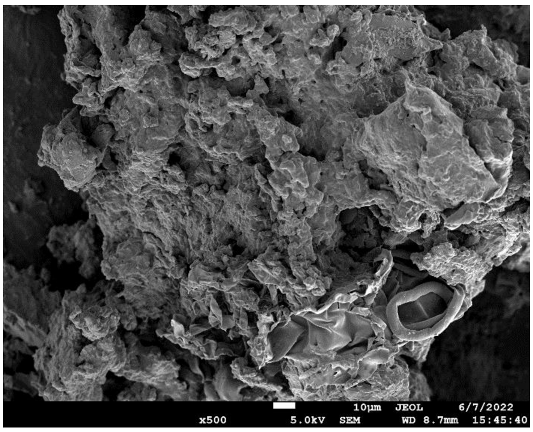
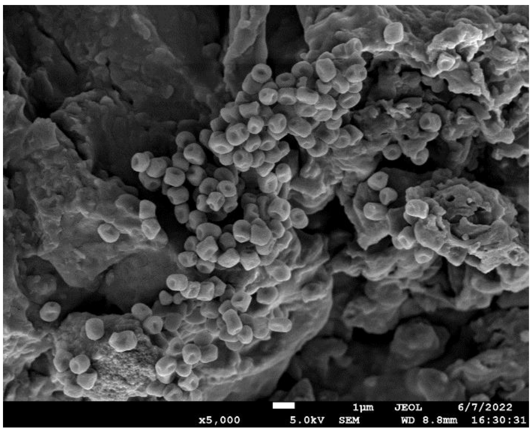


Figure 3. Dry Density versus Moisture Content of Peat Soil

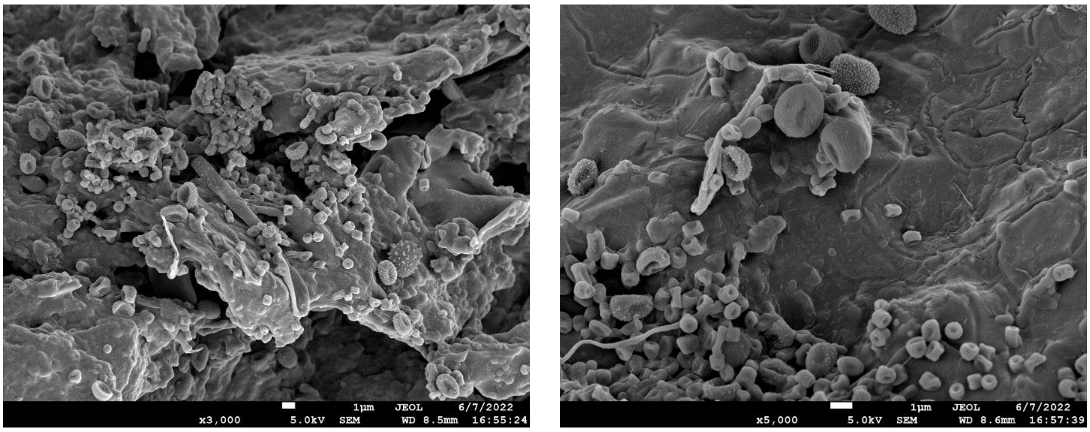
Figure 4 shows the scanning electron microscope (SEM) of peat treated with NaOH. Correspondingly, peat soil can clearly be seen to have a high micro-structure of voids in the form of high porosity, as shown in Figure 4-a. In fact, it is clear, as stated, that internal microcracks are accompanied by hydration products [26]. Figure 4-b shows the presence of a small, uneven distribution of microcracks and rounded materials in the stabilized soil with the addition of 5% NaOH. These microcracks could be attributed to the presence of NaOH particles. This phenomenon has been discussed as the stabilized peat soil exhibits small expansion during the hydration process while the peat soil shrinks as the moisture is reduced [26]. In this study, it is identified as a crystallization process and visibly shown to attach to peat particles, as consistently shown in Figures 4-b, 4-c, and 4-d. The crystallization process occurred when a chemical substance attached to the peat particle, as described previously [27, 28].



(a) Untreated peat soil



(b) Peat Soil with 5% of NaOH

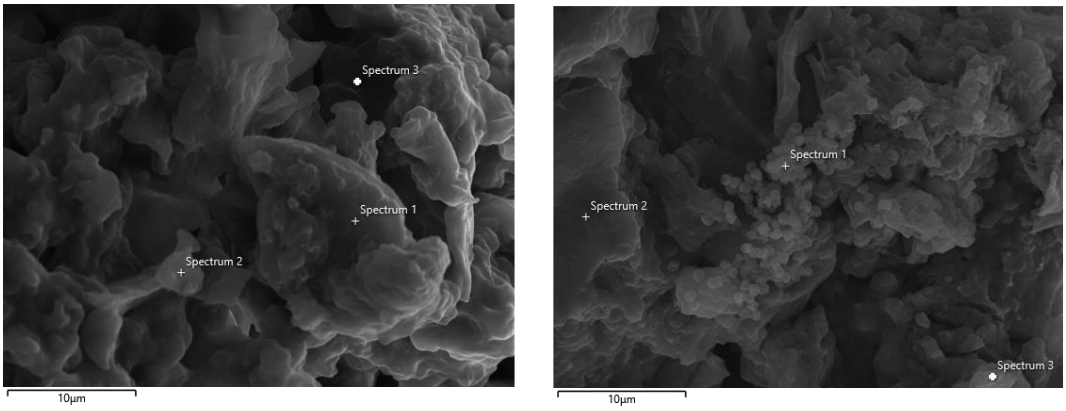


(c) Peat Soil with 7% of NaOH (d) Peat Soil with 9% of NaOH

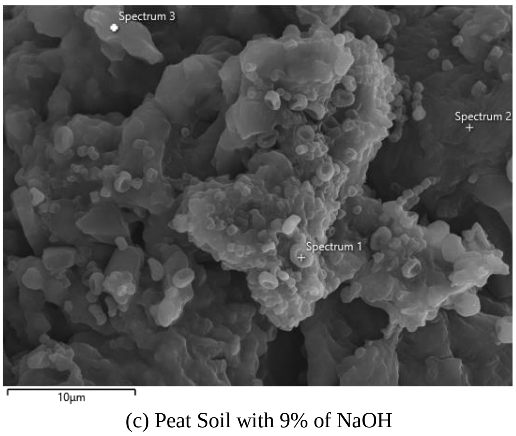
Figure 4. Scanning Electron Microscope (SEM) of peat and treated with NaOH

The morphologies of samples stabilized with NaOH demonstrate additional hydration with fewer microcracks. This is seen due to the migration of chemical substances generated by NaOH into peat soil. The reaction of peat towards NaOH assisted with the water content in peat to expedite the absorption where the natural behavior of NaOH is soluble with water. As discovered in Table 1, the pH value of peat is acidic, with a pH value of 4.0 [13]. NaOH is 13, which is classified as alkaline [12]. The encountered phenomenon between both regimes causes the formation of contemporary elements that fill voids in the peat microstructure.

Consequently, the honeycomb surface and pores segment in the peat microstructure are squeezed and flatter, as shown in Figures 4-b, 4-c, and 4-d, compared to the origin peat in Figure 4-a. In addition, the more NaOH substances in peat, the more the peat structure squeezes and becomes flatter. The NaOH particles observed penetrated the peat pores as a result of chemical reactions with the peat materials. The process absorbed water from peat and changed the dry density behavior of peat soil. The process is identified as the cause of the alteration of peat soil dry density. Figure 5 shows the energy dispersive X-ray analysis (EDX) spectrum absorbent with NaOH. Specifically, to illustrate the identification elements in peat treated with NaOH, it can be clearly seen that there are three (3) identified spectra, as in X-ray analysis in Figures 5-a, 5-b, and 5-c. The identified spectra developed from various elements recognized as carbon, oxide, calcium, aluminum, silica, natrium, and magnesium as major chain elements listed in Table 3, where peat soil chemical elements treated with NaOH are shown.



(a) Untreated peat soil (b) Peat Soil with 5% of NaOH



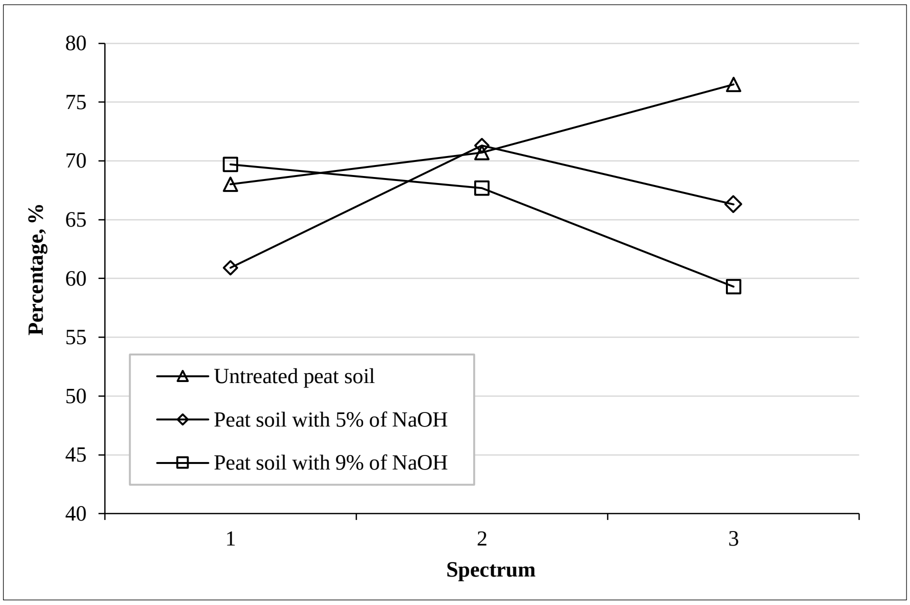
(c) Peat Soil with 9% of NaOH

Figure 5. Energy Dispersive X-Ray Analysis (EDX) spectrum absorbent with NaOH

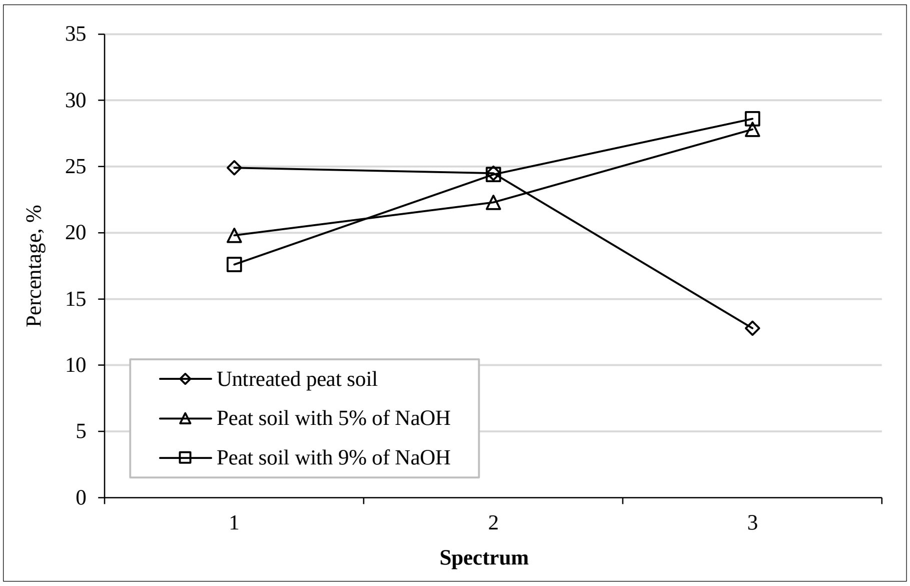
Further, Table 3 summarizes peat soil chemical elements untreated and treated with NaOH. As a result, there are very significant differences for each spectrum observed. The carbon C element shows a significant change from spectrum 1 to 3 in untreated peat, as shown in Figure 5-a. The carbon contents for spectra 1 to 3 slightly increased from 68.0% to 76.5%, respectively. This shows that untreated peat has a high carbon content without alteration. Subsequently, the results contradict those of treated peat with NaOH at 5% NaOH and 9% NaOH. Figure 5-b shows the peat element treated with NaOH 5%, and the carbon content significantly decreased in spectrum 2 from 71.3% to 66.3%. Similar trends developed with peat elements treated with NaOH 9%, where, from spectrum 1, the carbon content decreased from 69.7% to 59.3%, as shown in Figure 5-c. These changes were observed as altering carbon content due to modifications in peat from the hydration process and crystallization. In consequence of the alteration of carbon content depicted in Figure 6-a, changes in peat and NaOH elemental. The behavior of carbon peat changed from an uptrend to a downward trend. This shows that the elimination of water from peat effects from the NaOH reaction occurred and transformed the element into other properties such as oxygen, O, and sodium, Na, as in Figures 6-b and 6-c.

Table 3. Peat soil chemical elemental treated with NaOH

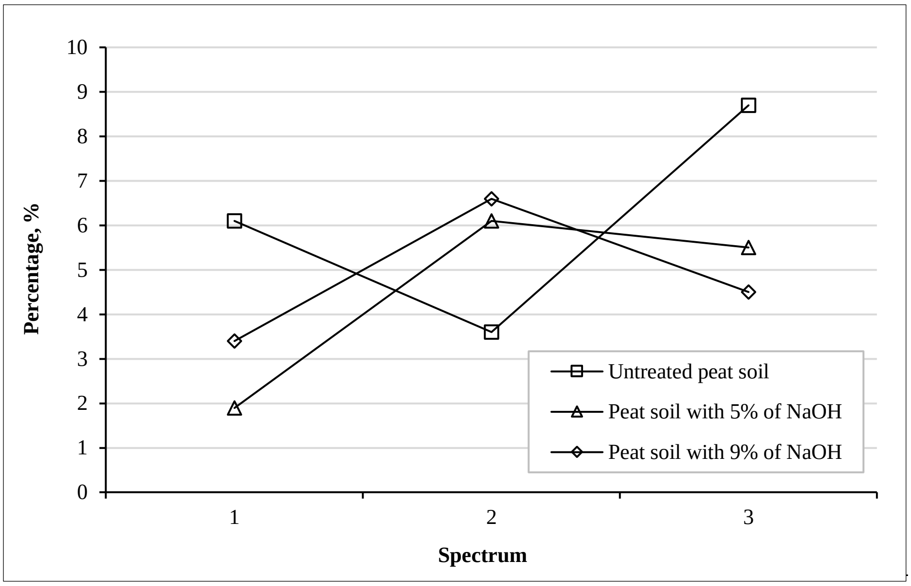
Properties	**Untreated peat soil**			**Peat Soil with 5% of NaOH**			**Peat Soil with 9% of NaOH**		
Spectrum	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
C	68.0	70.7	76.5	60.9	71.3	66.3	69.7	67.7	59.3
O	24.9	24.5	12.8	19.8	22.3	27.8	17.6	24.4	28.6
Ca	0.1	0	0.3	0	0	0	0.4	0.1	0
Si	0.1	0.4	0	0	0	0.1	0.2	0.5	0.1
Na	6.1	3.6	8.7	1.9	6.1	5.5	3.4	6.6	4.5
N	0	0	0	16.2	0	0	0	0	7.3
Zr	0	0	0	0	0	0	1.5	0	0
S	0.4	0.2	1.2	0.2	0.2	0.1	0.3	0.4	0.2
Mg	0	0.1	0	0	0	0	0	0	0
K	0	0.1	0	0.5	0	0	0.3	0	0.1
Fe	0.3	0.1	0.3	0	0.1	0.1	0.1	0.2	0
Ai	0.1	0.3	0	0	0	0	0	0.2	0



(a) Carbon, C element



(b) Oxygen, O element



(c) Sodium, Na element

Figure 6. Changes in peat and NaOH elemental

As a consequence, the oxygen content increased when peat was treated with NaOH with 5% of NaOH and 9% of NaOH, as shown in Figure 6-b. The oxygen trend increased when treated, and the oxygen content decreased for untreated specimens. The oxygen content of 53% of the untreated specimen increased from 66.3% to 76% for treated peat with NaOH with 5% NaOH and 9% NaOH. The recorded increment in oxygen content changed from 13.3% to 23%. Under those circumstances, the sodium (Na) content decreased significantly with increment of oxygen (O). Sodium content decreased from 8.7% for untreated specimens to 4.5% and 5.5% when peat was treated with NaOH, with 5% of NaOH and 9% of NaOH. The phenomenon can be explained by the fact that conversion affects the nutrient content of peat soil [29].

4. Conclusions

The average moisture content of peat soil was determined to be 550%, which is due to climate change as a result of changes in temperature, precipitation, and rainfall influencing soil saturation intensity, in which the water table forms in a horizontal plane and may emerge at a level greater or less than the actual water table. The average pH value of peat soils found is 2.3, suggesting that they are acidic. This would have had an influence on the acidic component of peat soil due to its location and decomposition processes. The specific gravity of peat is greatly affected by its composition and percentage of inorganic components. It is related to the degree of decomposition and mineral content of peat. The ratio of the unit weight of solid particles to the unit weight of water is referred to as the specific gravity of a soil. Because specific gravity is a dimensionless measure that indicates the ratio of two different densities, it should not be confused with soil density. The average specific gravity of peat soil is 1.47. The unit weight of peat is 1.04 g/cm^3 and the specific gravity is 1.4. This physical characteristic indicates that peat is a highly soft soil with a water-dominated structure. From the laboratory testing of organic content, the average loss of ignition is 96%. The organic content of peat soil is between 53.97- 95.51%. In this study, the result of the fiber content test was 75.92%, which can be classified as fibrous peat. Fibrous peat soil is known for its high fiber content (FC) and organic content (OC). The characteristics of peat land with fibrous peat soil are not the same as those of clay soil because of the different soil properties and structures. For the Von Post scale test, it can be justified that the class of humification of peat soil at Klias, Beaufort, is H5, where the peat is dark brown, turbid water with no organic solids squeezed out. It only released very muddy water with a very large amount of amorphous granules that escaped between the fingers.

As peat soil is seen as troublesome due to its uncertain behavior, determining its index qualities is critical. All test results were considered acceptable when compared to previous research done by various researchers. The difference obtained with previous researchers is due to certain factors, for example, the site condition, changes in weather, and changes due to agricultural activities. The site location of the samples is also one of the causes of the different values obtained from the findings. The major finding was that the mixture of peat soil with a higher concentration of NaOH will give the optimum result from the graph of moisture content versus dry density. From the results, it can be clearly seen that the mix with a lower concentration of NaOH will have a higher dry density. Thus, this study strengthens the idea that adding NaOH to peat soil can enhance the properties of soft peat over a period of time and concentration accordingly. NaOH has been observed as an alteration agent for peat soil dry density. It can be seen clearly that 5% NaOH is the dry density of the peat with the lowest moisture content and is suitable as a peat soil stabilizer. The increment of oxygen content recorded changes from 13.3 to 23%, while the sodium (Na) content decreased significantly with the increment of oxygen, O. Sodium content decreased from 8.7% for untreated specimens to 4.5 and 5.5% when peat was treated with NaOH with 5% and 9% NaOH, respectively.

5. Declarations

5.1. Author Contributions

Conceptualization, H.M.M. and M.F.I.S.; methodology, H.M.M.; investigation, M.F.I.S.; writing—original draft preparation, H.M.M., M.F.I.S., A.E.A., and S.N.F.Z.; writing—review and editing, H.M.M., M.F.I.S., A.E.A., and S.N.F.Z. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

Data sharing is not applicable to this article.

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5.4. Conflicts of Interest

The authors declare no conflict of interest.

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