Determination of In-Situ Density and Physical Properties with Microstructure of Klias Peat Soil

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ABSTRACT In Sabah, peatland can be found across Papar, Beaufort, Klias and Bukau in western region of North Borneo Island. With distinct behavior in peat soil, it provides growing consideration and limitations, it has various special characteristics and different from other types of soil. In this research, the physical profile and index properties of peat soil have been investigated through field and laboratory testing methods. Peat categorized as uncertainty material that has high compressibility and variety of index properties. In Klias peninsula where peat abundantly exist, has not recorded any engineering studies and the information of its index properties are inadequate. Thus, this study conducted to determine in-situ density and physical properties of peat soil classify peat soil in engineering terms. Modified peat sampler used to collect sample from various level of depth from soil surface to almost 5.0 m depth where boundary of peat zone and marine clay zone found. In-situ density of peat carried out simultaneously during sampling works of each increasing depth with interval 0.5 m. Disturbed sample analyzed in laboratory to determine the index properties. SEM imaging represents microstructure analysis of Klias peat soil. There are substantial significant relationships between peat behaviour against depth and consequential properties discovered. Both zones of peat and marine clay have significant correlation. The pH value was in the range from pH 4.80 to pH 5.25. Certainly, high pH acidity of mixed-layered at 5.0 m level are believed due to the predominantly present of clay soil content in peat element. In-situ density of peat increasing proportionally to the depth of sample taken using peat sampler.

KEYWORDS: Peat; In-situ density; Organic content; Index properties; Microstructure.
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INTRODUCTION

Klias is located in the district of Beaufort, Sabah which is situated in Northern part of Borneo Island with an estimated area 1,735 km^2. The land is on peat are estimated 3,620 hectares was still covered as protected area for peat soil were declared as forest reserve. The remaining land on peat soil were cleared use is for agriculture. An assessment of physical and chemical properties has been conducted for Klias peat soil with identification and classification which is mainly contributed in determination of index properties and characteristics of Sabah peat soil, in general. The activity includes peat soil field investigations that focused on the depth and type of peat that covered the area that located in Kampung Padas Valley which is adjacent to the boundary of Klias Peat Swamp Forest Reserve. In total, 30,900 ha of Klias was gazette as a Forest Reserve, in 1980 it was degazetted (Wetlands International, 2010) and paved the way for development. In general, the index properties of peat soil characteristic from Klias, was undiscovered in engineering perspective. There is still insufficient data and information to classify peat soil at Klias Peninsular.

A study on peat soil was conducted in southern region area in Beaufort at Lumadan have found that, the thickness was varying ranges from 1.0 m to 3.5 m with hemic peat type (Zainorabidin & Mohamad, 2016a). Peat soil mainly consists of unrecognizable decomposed plants material with blackish-dark or brownish colours.

In some extend, peat contents of sand, silt and clay under damp and anaerobic condition (Sa'don *et al.*, 2014). Peat formed due to the decomposition of organic matter such as plant remains, leaves, trunks and roots (Kolay & Aminur, 2011). Conversely, priority is given to develop areas and classified as disturbed peat for land use conversion mainly under agricultural and development of infrastructure like embankment, road, canal and drainage. Hashim & Islam (2008) found that, the ground water table for peat soil is below 0.3 from top surface, and pure peat is up to 1.5 m. Preliminary exploration, conducted by Zainorabidin & Mohamad (2016b) consists of a several of prospecting in identification of Sabah peat soil. This study was carried out in Beaufort area and in the findings, they have discovered the moisture content are ranges from 489.09% to 985.30%. Consequently, Peat has high compressibility factor when peat is loaded with a force and causes peat formation to deform in the direction of the applied force. For tropical condition, fibric peat will cause highest settlements followed by hemic and sapric when subjected to any load over the time period (Duraisamy *et al.*, 2007).

Domed structure appears for most of the peatland areas in the coast of Malaysia and fairly uniform in depth and elevation (Wetlands International, 2010). Peat depth at the centre of the dome may reach 12 m, such as in the inland domes around Marudi in Sarawak (Anderson & Muller 1975). Fox (1972) reported that highly developed peat domes and their associated peat swamp forest communities such as those found in Brunei and Sarawak, are absent in Sabah. For this reason, this study was conducted to discover the convex dome shape in Klias peatland area. The main objective of this study is to examine the peculiar engineering behavior and characteristic of Klias tropical peat with respect to index properties such as fiber content, organic content natural water content, liquid limit, specific gravity and type of tropical peat were discovered and compared to other areas in Malaysia. The convex domes explored by using peat sampler method in various location in Klias Peninsular. The findings provide information of Sabah peat soil properties.

SITE EXPLORATION

Klias Peat Soil Location and Formation

Ordinarily, the main location of the study area is located at the outside of the forestry zone and situated in palm oil plantation and agriculture area. In the foreground, the state of the area consists of plants and trees that develop the area from varies species of dactylocladus stenostachys and dryobalanops rappa, known as an important habitat for the endemic plants of Borneo peat as found in Sarawak by Tawan *et al.*, (2008). The vegetation of the Klias peat is mixed peat swamp forest and agricultural plants. In terms of species composition, identically it is very similar in Brunei Darussalam which is recorded in peat swamp species (Din *et al.*, 2015). Figure 1 shows the location of Klias-Beaufort, Sabah peat study area. This area was referred as Klias Peninsular and all samples and location here after are named with KPpt to address the location. The surface condition was spongy and classified as very soft. Self-weight of object can easily stress the peat soil and quick settlement happened when walking on it. The Klias Peat Swamp Forest Reserve field topography formed in flat terrain.

The ground water table was observed 0.3 m from surface and measured outside of the rainy season or known the minimum rainfall pattern that occurs in February every year (Zainorabidin & Mohamad, 2016a). Throughout visual inspections on the peat soil study area, we have identified the surface soil physical characteristic covered with topsoil mainly consists of unrecognizable fibrous plant materials, brownish in colour and highly compressible. Figure 2 shows the fibrousness soil surface condition in Klias Peninsular.

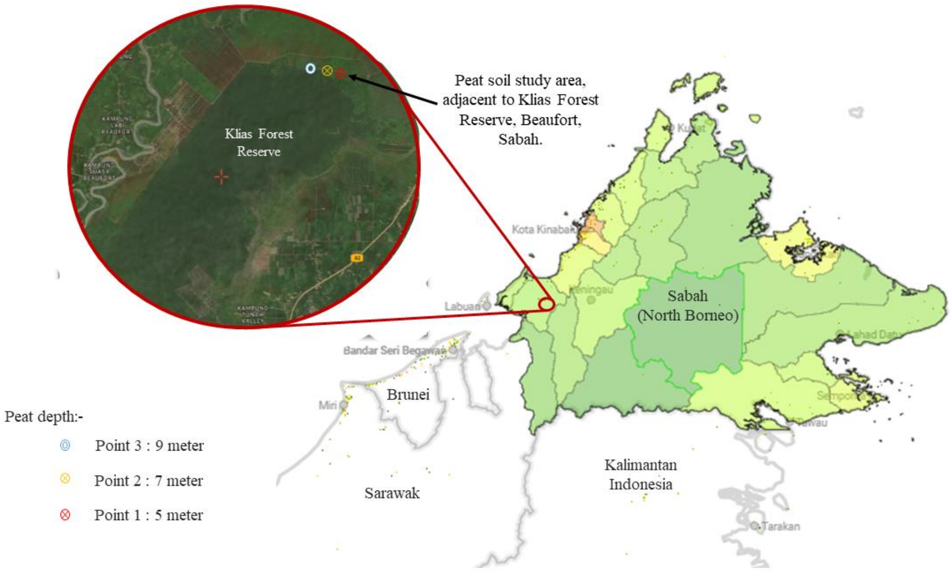

Figure 1. Klias-Beaufort, Sabah peat location adjacent to Klias Forest Reserve.

Figure 2. Depict view of Klias-Beaufort, Sabah peat area adjacent to Klias Forest Reserve.

METHODOLOGY AND TESTING PROGRAMME

This study conducted in Klias, Sabah where peat abundantly exits. The investigation programme was started with field study which are incorporated with profiling peat strata and identification of humification of peat in field using peat sampler and Von Post scale. Laboratory test carried out with microstructure of peat by using Field Emission Scanning Electron Microscope (FESEM). These electrons are liberated by a field emission source to identified and imaging peat sample.

Visual interpretation of a soil layers has been conducted using peat sampler to take an undisturbed sample at predetermined depths for 3 points to measure the locally thickness of peat soil layers. Sample extracted with a length of 50 cm and penetrated every 0.5 m interval up to soft clay border to illustrate the peat soil profiles. Samples collected at different depths and up to reach the clay layers. The peat sampler manually pushed into peat soil from ground surface. The sample blade containing part of cylinder with half diameter about 55 mm. Constant volume of peat determined by 0.15 m height and 0.025 m diameter filling inside the sampler. The first point selection is initiated at the position between the palm oil plantation and the Forest Reserve buffering zone as shown in Figure 1. Point 1 as shown in Figure 3 where peat profile discovered 5.0 m thick which is peat visually categorized as peat to medium grained woody hemic and clay.

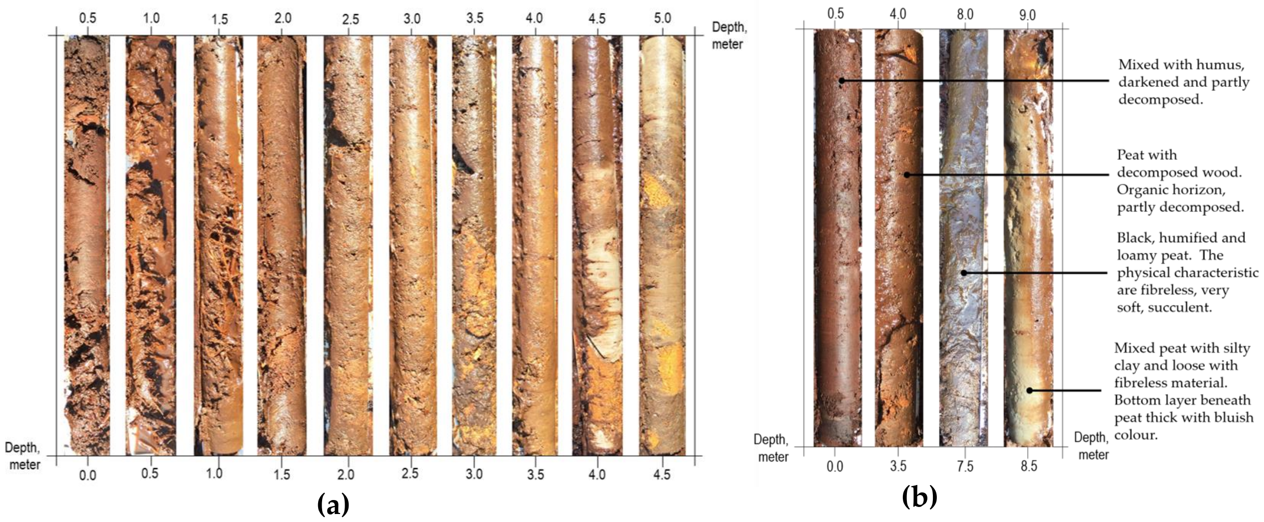

Figure 3. Point 1, 5m peat thick zone of peat to medium grained woody hemic and clay (a). Point 3, 9.0m thick peat to clay zone (b).

From 0.0 to 1.5 m depth and considered shallow peat, it can be clearly seen that, peat profile is loosen, uncompressed with vast spaces between soil material including voids. Generally, the peat layers consisting decomposed material for the entire structure such as roots and plants with extremely soft condition. Denser conditions were observed after depths of 2.0 m to 5.0 m. Increased in depth and water pressure are believed to cause higher stress that formed the condition very tightly packed together than the upper layers. Significantly, the deeper peat layers, the denser and less void it becomes. Apparently, even at a depth of 5.0 m, there are woods and plant materials which is identified as a decomposition component. With a slightly darker and brownish colour at the top, it becomes brighter on the layers closer to the clay.

Afip & Jusoff (2019) extracted peat sample at depth of 2.0 m for humification study at field. Thus, the humification study have been conducted in this study are set to be more than 0.5 m. The exploration of peat depth measurement on field continued for the point 2 and located straight-line to the north at 200 m away. As a result, deeper depth of peat has discovered as shown in Figure 4. At this level, peat accumulation at 7.0 m deeper compared to point 1. Analogous to shallow structure, the profile similar to point 1 which is uncompressed and highly compressible. In particular, from points 1 to 2, it was discovered that deep peat occupying the gentler slopes and declined depth. From top profiles at 0.5 m to 7.0 m, the peat in brownish to darker blackish-grey colour. Closer to 7.0 m to 7.5 m, clay soil with bluish-grey colour collected. At 7.5 m depth, the clay categorized as soft clay due to its very soft condition.

Woods and plant materials are clearly visible in deeper depth at 7.0 m. The accumulation of partially decayed vegetation and trees with organic formed the habitat. Figure 4 shows the point 3, 9.0m thick peat to clay zone. Point 3 located 500 m from point 1 and 250 m from point 2. It was discovered that, at point 3, the thickness of peat is 9.0 m. Surprisingly, the accumulation of peat in

Klias peninsular are discovered consistently sloping in blanket peatland. The slope shape looks like a curve or the convex dome. Unfortunately, the mid of the shape was not continued to discover.

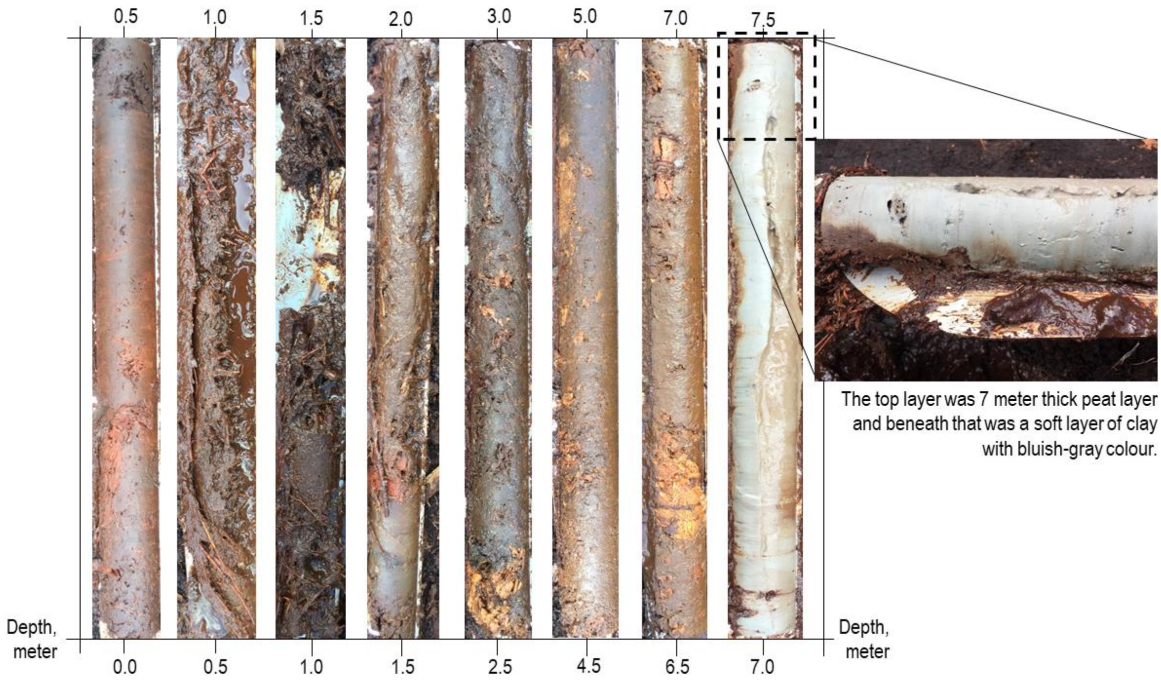

Figure 4. Point 2, 7 m thick peat to > 7.5 m of clay zone with bluish-grey colour.

Above all, the difference of depth shows the indicative slope shape and peat thicknesses where curves drew in like dome or convex identical. At the southern part of Klias Peninsular, which is at Lumadan, Beaufort area, the same slope profile shape was discovered from 1.0 m to 3.5 m depth (Zainorabidin & Mohamad, 2016b). Under those circumstances, the physical properties of peat remained copied the adjacent layers where it exists.

Figure 4 shows the vertical section of the peat soil that is exposed by a peat sampler for point 3. Mixed with humus, darkened and partly decomposed material was formed on top soil level between 0.0 to 1.0 m where, the organic horizon accumulated. Black, humified and loamy peat make up the layer that very soft and succulent. To depth of 8.5 m, the peat material was very moist and no rock fragment. At deepest level, 9.0 m thick peat, the underlying sub-soils are identified as acidic sulphate clays. The pH value was more than 5.0. Silty clay and loose material identified as well at the bottom layer beneath peat thick and Odorless. Von Post scale are conducted to visually classify the peat. pH test also conducted to study acidic or alkaline against depth, where the acidic behaviour could be known.

RESULT AND DISCUSSION

Figure 5 shows the method of measuring of Von Post scale and technique. A sample from 1.0 m depth was collected and measured for this purpose. By using one hand with the fingers full of wet soil and hardly squeezed until water extruded through the fingers. The colour was very dark-brownish and the fiber quantities remaining on palm has decreased to 60%. Releases muddy water and slightly pasty.

Referring to the Von Post scale, the samples scored H5 class and visually hemic peat type. With regards to Sabah peat soil, H4 until H7 discovered in Lumadan area (Zainorabidin & Mohamad, 2017). Compared to other places in Malaysia, Logan Bunut in Sarawak recorded H2-H4 scale and classified as very deep peat that quite humified in nature condition (Melling *et al.*, 2006). In Sibu, Sarawak peat on the depth 1-1.5m was amorphous peat with H8 scale, while in Parit Sulong, Johor at the same depth it's also noted H8 (Teong *et al.*, 2016). These differences are compared to the environmental conditions of the peat origin and its essential index properties. The geography and the nature of the peat in the islands of the North Borneo separated from other continents make it even more significant.

(a) **(b)**

Figure 5. Von Post classification of Klias peat soil. Squeezing in palm produces dark-coloured water (a). Palm squeeze results with H5, little decomposed peat (b).

Without doubt, from these 3 locations in Klias area, the scale degree of humification observably different which are, the shallow peat from 0 to 1.5 m mainly consists of incompletely decomposed material and structurally formed with the root system of a plant that constantly consists in that range whether bare root plants are dormant, perennial plants or actively growing as the location an active agricultural area and neighboring with Forest Reserve.

Acidic rate of peat accumulation

Peat consists the accumulation of decayed plant material and burial of organic particles. The acidity of soil was found to be highly correlated to the decomposition rate (Mohamed *et al.*, 2002). pH test was conducted in laboratory for samples from point 1. Peat soil sample collected from 0.5 m to 5.0 m. Figure 8 shows the different pH rate in each soil depth which is at depth of >0.5 m peat has more than 4.20 pH value and categorized as acidic. From the results, it can clearly be seen how pH rate and depth have always relationships. The deeper the peat, the higher the pH value. At 0.5 m depth, the acidity was 4.25 and in the middle is about 4.30 occasionally, there are uncertainty values in certain depths, which also shows a gradual increased. To further depth at 5.0 m, the rate of pH was increased to 4.60. Compared to other Borneo peatland, the pH value in Loagan Bunut Forest Reserve range is between 3.3 - 3.75, lower than Klias Forest Reserve (Tong *et al.*, 2015). Peat at Tun Zaidi Stadium, Sibu reported range from 3.59 to 3.62 (Kifli *et al.*, 2016). Kolay & Aminur (2011) have recorded, in Sarawak the pH value of the peat soil sample is 4.05, which is more acidic.

The higher the pH, the greater the decomposition rate as cited by Mohamed *et al.* (2002) and in line with Klias peat characteristic pH rate. In the first place, Andriesse (1988) have discussed mainly regards the variations within this range that caused by the admixtures of mineral soil which generally increase the pH and by specific locations in the peat swamp. The increment of soil acidity is more noticeable at deeper peat soil nearly clay layers. Following this, mixed-layered of peat and clay observable at depth 5.0 m.

Obviously, the formation of soil at this peat layer are dependent on clay sedimentology that more dominants compared to the distribution of peat soil. The pH rate comparisons of clay soil in Sabah

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were done to evaluate the pH content of this acidic soil which is expected to resemble with clay. Compared to the pH value of origin clay soil, the acidity content is higher than peat. In fact, the pH value was in the range from pH 4.80 to pH 5.25 and shows acidity to neutral soil. Moreover, the pH value for clay in Sabah also surpassing neutral value to be alkaline at range 7.09 to 8.48 (Musta *et al.*, 2019). The pH alkalinity and acidity of soil dependents to the existence of carbonate rocks as one of the parent rocks in the particular outcrops. Certainly, high pH acidity of mixed-layered at 5.0 m level are believed due to the predominantly present of clay soil content in that peat element.

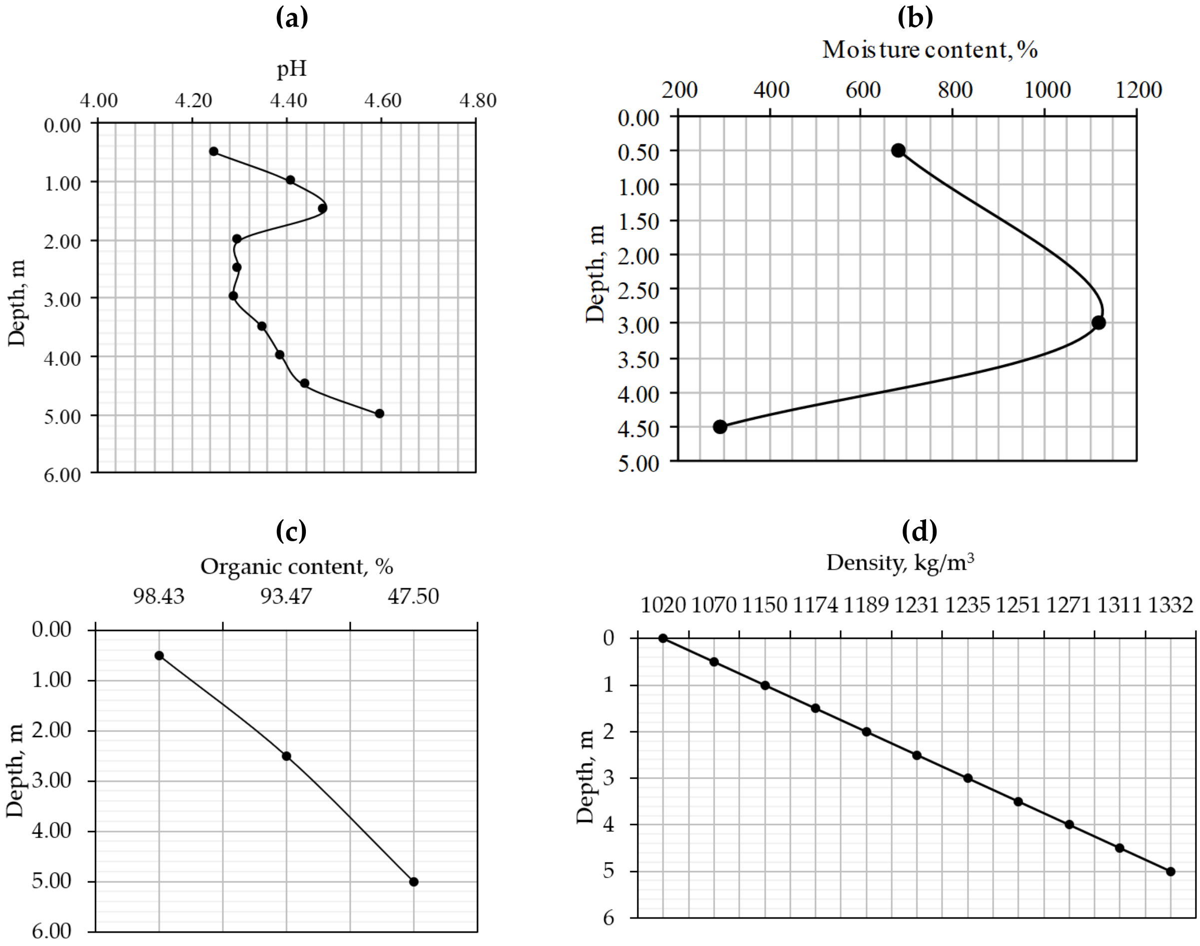


Figure 6. pH test value for Klias Peat (KBSpt). Depth, m against pH value (a), Moisture content versus Depth, m (b), Organic content versus Depth, m (c) and (d) In-situ density, kg/m^3 versus Depth, m.

Figure 6(b) shows the moisture content versus depth of peat soil in Klias. The result clearly shows that, in peat soil zone from 0 m to approximately 4.0 m, the moisture content increase with depth. The deeper the peat zone, the higher moisture content due to the basin shape of beneath peat surface and retain higher water content. Except, for depth more than 4.0 m, the moisture content decreased to 280%. This is due to the soil sample at 4.5 m is sapric peat which is similar to marine clay soil that formed the basin base. As a matter of fact, organic content as can be seen in Figure 6(c) depict similar behaviour as moisture content. In general, moisture content and organic content has significant relationship towards depth of peat. These behaviors contemplate the peat layer that occurs during the accumulation process.

In this study, relationships between the in-situ density of peat and the depth of peat profile in Klias are studied. Figure 6(d) displayed the results of in situ density against the depth of peat on field that have been done in Klias, Beaufort, Sabah. Based on the Figure 6(d), results in-situ density of peat increasing proportional to the depth of sample taken using peat sampler (refer Figures 2 and 3). From Figure 6(d), it can be seen that, the lowest value of density of a fresh peat is from the top soil of peat at 0 m - 0.5 m which is 1020 kg/m^3 and the highest value is 1332 kg/m^3 which is at the depth of 3.5 m - 4.0 m. These results related with physical characteristic of peat profiles. This result shows the correlation in increasing of density peat to the depth due to the increment of stress and demonstrated self-consolidation are occurred in peat soil.

Index Properties of Peat Soil

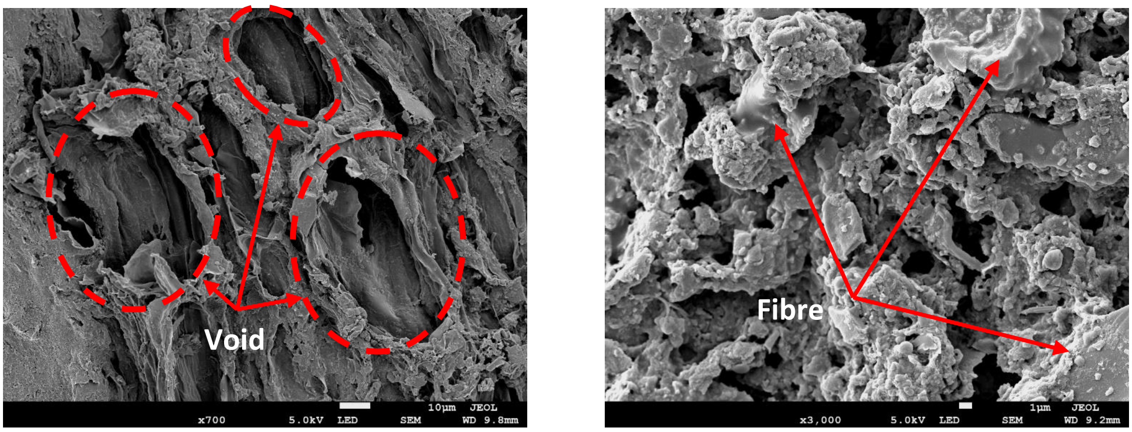
Table 1 indicated that the index properties of Klias peat soil. The moisture content of Klias peat is 687.03%. Klias peat indicated the percentage of organic content at 98.94%. These results are influenced by the soil condition which originally contained leaves, roots and decayed materials. The percentage of fibre content indicated as 66.41% which proved that the peat is classified as hemic peat type. Liquid limit for Klias peat expressed at 168.154%. In general, the basic index properties of peat, such as moisture content, fibre content, organic content, pH, liquid limit and specific gravity and groundwater level are also essential for behavior of in situ density and governed by in-situ parent material that formed peats. These results are influenced by the soil condition which originally contained leaves, roots and dried grasses (Adon *et al.*, 2012).

Table 1. Index properties of Klias peat soil.

Index properties	Rate
Natural moisture content (%)	687.03
Specific gravity	1.65
pH	3.25
Fiber content (%)	66.41
Organic content (%)	98.94
Liquid limit (%)	168
Von post classification	H4
Peat type	Hemic

Klias Peat Soil Microstructure

Peat consists the accumulation of decayed plant material and burial of organic particles. Thus, the development of peat fibre mainly contributed by decayed plants material. The microstructure of Klias peat soil is presented in Figure 7. From the SEM images, it can be clearly seen that, peat material composed with decayed plants fibre which is has higher void and pores. This fibre structure seen as factor that contributes to the higher moisture content in peat soil that believed as agent that hold water in trap pores. The microstructure of a material has interdependence with mechanical and physical characteristics (Gleize *et al.*, 2003).



(a) **(b)**

Figure 7. SEM micrograph of Klias peat soil, (a) 0.5 m depth, (b) 0.7 m depth.

CONCLUSION

Peat soil is not only soft, it is compressible to where this characteristic will lead to excessive settlement which is a very serious problem. Generally, peat soil is considered as a soft soil as it has high settlement value even under moderate loading condition. This study has discovered that, peat profile at 5.0 m thick which is peat visually categorized as peat medium grained woody hemic and clay. From 0.0 to 1.5 m depth and considered shallow depth, it can be clearly seen that, peat profile is loosen, uncompressed with vast spaces between soil material including voids. Generally, the peat layers consisting decomposed material for the entire structure such as roots and plants with extremely soft condition. Klias peat soil scored H5 class and visually hemic peat type according to Von Post scale. The geography and the nature of the peat in the islands of the North Borneo separated from other continents make it even more significant. Certainly, high pH acidity of mixed-layered at 5.0 m level are believed due to the predominantly present of clay soil content in that peat element. This study has discovered also that, the deeper the peat zone, the higher moisture content due to the basin shape of beneath peat surface and retain higher water content. In general, moisture content and organic content has significant relationship towards depth of peat. These behaviors contemplate the peat layer that occurs during the accumulation process.

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