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Physical Properties of Undisturbed Tropical Peat Soil at Pekan District, Pahang, West Malaysia

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Abstract: Peat soil are considered soft soil with having weak characteristics such as low shear strength, high moisture content, and compressibility. Construction perspective, peat soil is considered as unstable soil due to its poor engineering properties. It may cause an extensive loss in road or building construction projects. The key objectives of the current study are to examine the physical properties of peat soil including shear strength, liquid limit, moisture content, organic content, pH, and dry density of peat soil in Pekan district. The peat samples were collected from Kampung Bahru (KB), Kampung Lancing I (KLI), and Kampung Lancing II (KL II), Pekan District, Pahang, Malaysia. The finding indicates that the shear strength (kPa) for was measured in between 7.2 to 8.2 kPa. The water content was recorded 537.10 % to 635.28 %. The liquid limit was examined 137.638% to 152.540 %, the maximum dry density was examined 6.68 x 10-7 kg/cm^3 to 7.99 x 10-7 kg/cm^3. The average organic content was calculated as approximately 95.88 % to 98.48 %. In comparison with previous study, its indicated that the investigated peat soil in Pekan area is mainly content with lower shear strength, high water content, liquid limit, and low density, resulting in low strengthening properties. Based on the examined physical properties, its specified that peat did not have adequate stability as a road or building foundation. Strengthen of peat are highly recommended for any types of construction on peatland in Pekan district, Pahang, Malaysia.

Keywords: Peat soil, shear strength, moisture content, liquid limit, Pekan

1. Introduction

Soil is considered an indispensable natural resource is accompanying future infrastructure and agricultural expansion [1], [2]. Peat soil has been deemed a type of soft soil, stated a challenging soil from a construction viewpoint, but sometimes its natural state is not suitable for cultivating different crops because of its high acidity [1], [3]. Peat is formed from the plant's matter in an incomplete decomposition process [4]. During peat formation, the

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biochemical process ensues to the accumulated plants and vegetative materials under an anaerobic condition with water, sunlight, internal temperature, macro, and microorganism, which ultimately precedes the partial production of organic material. Its physicochemical and engineering properties are different based on the fibres' deposit formation, humidity, temperature, and origin [5]. The physicochemical properties of soil particles are highly dependent on their material structure; organic material is a significant binding material for soil aggregation, particularly soil with a high amount of organic matter [6].

Construction perspective, peat is a weak soil because of its poor properties such as high organic content, low shear strength, high moisture content, high permeability, and compressibility with poor mechanical performance. Any kind of construction on peat has become a great challenge for engineers around the globe. Generally, peat soil exists in all tropical countries of the world. Malaysia contains approximately 0.5 billion hectares of peatland, which covers 4.0 % of the world's whole peatland, with the sixth-largest peat reservoirs in the world. In this region, peatland is mainly used as cultivation land (palm oil, pineapple, and banana) and nominal economic value except for farming interests [7]. Hence, construction on peatland in Malaysia has become more complex, and road embankments have experienced many challenges, including high instability, excessive settlement, landslides, embankment, and slope failure during or after construction [4]-[8]. To enhance soil's engineering properties, different techniques have been deployed, including chemical and mechanical methods, considered the oldest technique in the world [9]. The physical properties of Malaysian peat are tabulated in Table 1, and detailed properties of peat are explained below.

Table 1 - The physical and chemical properties of Malaysian peat soil

Location	Shear strength (kPa)	Water content (%)	Organic content (%)	Liquid limit (%)	Degree of Humification	pH	References
Parit Lapis Kadir (Johor)	10.7	476.849	97.286	152.333	-	-	Wahab [8]
Parit Haji Ali (Johor)	8.8	476.849	97.60	136.107	-	-	Wahab [28]
Parit Nipah (Johor)	9.9	502.594	97.88	182.534			
Parit Nipah (Johor)	25	545	80.32	360	-	-	Mahmod [32]
Penor (Pahang)	-	676.30	80.32	149	H6	3.68	Adnan [33]
Parit Nipah (Johor)	14	125.87	-	89.66	-	2.86	Ling [34]
Batu Puteh (Johor)	4	119.13	-	75.25		4.73	
Pontian (Johor)	3-17	898.91	76.55	255	H5	2.55	Zolkefle [35]
Pontian (Johor)	-	848.7	99	-	H4	-	Razali [36]
Parit Nipah (Johor)	-	784.40	95.44	-	-	-	Wahab [37] , Wahab [38]
Matang (Perak)	-	360–787	42–85	69–79	-	-	Aminur [39]
West Johor	7 -11	472	92	140.00	-	-	Adnan [40]
Klang (Selangor)	-	573–691	88-99	-	-	-	Wong [41]
Banting (Selangor)	-	140–350	70–88	240–398			Duraisamy [18]
West Malaysia	8.0 - 10.0	200–700	65–97	190–360	-	-	Shah [29]
Sibu, (Sarawak)	8-17	200–2200	50–95	125-297	-	-	Shah [29], [42]
Sibu, (Sarawak)	-	-	25–35	164–203			Firdaus [43]
Sabah	-	461.65-985.40	95.51-95.82	245	H6-H7	4.8	Adnan [20]

1.1 Shear Strength

The shear strength of the soil is also considered essential mechanical properties, that specific loading conditions and plays a vital role in evaluating the soil's foundation and slope stability [10]. The presence of minerals and high moisture content directly impacts the peat soil and leads to low shear strength [11], [12]. In the presence of high fiber content, the peat soil such as fabric, hemic, and sapric possess the shear strength from higher to lower. The author [13] mentioned if the undrained shear strength of peat is measured in the range of 6 and 17 kPa, and the most insufficient shear strength of the soil is because of the absence of cohesiveness of soil particles in the occurrence of extreme water as a lubricant [14]. According to the author [14], the undrained shear strength for Malaysian peat soil measured by field vane shear apparatus is between 3 to 17 kPa, while the average undrained shear strength for Malaysian peat ranges from 5 to 20 kPa is considered as pure peat soil [15].

1.2 Liquid Limit

Peat soil's liquid limit mostly depends on its fiber content, humification level, and proportion of silt and clay. If the organic content is high, its direct impact on the liquid limit and fibrous peat liquid limit is high, then the sapric peat. Generally, the average liquid limit for peat varies from 200 to 600% in the tropical region, while for bog peat, it is in the range of 800 to 1500 % [16], [17]. The liquid limit of tropical peat soil in Malaysia ranges from 130 % to 400% [18], [19], while [20] stated that the liquid limit for peat soil is 149% and 162%.

1.3 Ground Identification of Peat-Based on Von Post System

Usually, for the ground identification of peat soil, the decomposition degree is measured based on the von Post scale 1922, which recommended the field identification system to easily specify the decomposition or humification of peat soil, which is based on several factors such as botanical composition, moisture content, types of fibers inside the peat soil, and woody materials. In von Post identification, the degree of humification is indicated by the English letter "H," where it has a fixed range from HI, which expresses (less humified) to H10 (highly humified). Engineering point of view, these ten different degrees of decompositions scale modified von post system are reduced the coarse-scale with 3-5 degree of decomposition after [21], the lowered scale of von Post system is further introduced by [22] as shown in Table 2.

Table 2 - The recognition of peat-based on von Post system [17], [22], [44]

Category	Group	Nature
Fibrous peat	H1 – H4	Low degree of decomposition. More fiber. Easily recognized plant structure, low degree decomposition, High fiber content, easily recognizable plant structure.
Pseudo-fibrous peat	H5 – H7	The degree of decomposition is intermediate; Plant structure is recognizable
Amorphous peat	H8 – H10	The decomposition degree is high; Plant structure is not recognizable with soft or semi-liquid consistency.

1.4 Organic Content

Pure peat soil comprises high organic content with remains of plants and vegetative materials whose rate accumulation is faster than the decomposition rate with continuously slow organic matter decomposition process [23-24]. The high organic peat content leads to high moisture content [25]. The organic content of various peat soil types varies in the range of (25–98.46%) [17]. The organic content of Malaysian peat soils ranges from 70% to 98% [26-28, 19].

1.5 Moisture Content

The moisture content is considered a critical parameter for peat soil, which differentiates organic and inorganic soil. The peat structure contains a large pore space; the water moves quickly because the particles are away from each other, which allows a high amount of water in the soil. Furthermore, high buoyancy and pore volume provide a very low density is the second reason for the high moisture content [29]. The author [30] examined three kinds of water storage in peat sediments, where water held tiny cavities, large cavities, and physical and osmotic pressure. Generally, the fibrous peat water content is high because it contains large holes in plant materials [14]. Hemic peat contains less water-holding ability than fibrous peat because of the mineral's presence inside its particles. The capric peat has low water content because of its high mineral content. The water holding capacity reduces when the decomposition level increases because of pore structures' breakdown. The water holding capacity of Malaysian peat soil varies between 96 % to 2200 % [18], [29], [31], [32].

1.6 Peat Soil Distribution

1.6.1 Global distribution

Generally, peat soil exists in all tropical countries of the world [45-46] and covers approximately 0.5 billion hectares or 4.0 % of the world's whole land. Among this, near 95% of the peatland has existed in the northern hemisphere, and 20.3% (36.9 million ha) are found in Asia. There are two countries with an extensive peat volume, Canada, with 170 million hectares (mh), and Russia comprises approximately 150 (mh) as tabulated in 3.

1.6.2 Local distribution

Peat soil is considered a significant soil group that covers around 8% or 3 million hectares of Malaysia's total land. At the same time, Sarawak state comprises the largest peatland area, which covers about 1.66 million, Peninsular Malaysia about (0.98 m/ha) and Sabah state encompass (0.80 m/ha) peatland as can be seen in Fig. 1.

Fig. 1 - The peatland in Malaysia [47]

2. Method and Materials

2.1 Site sampling Area

The Pekan district is located about 35 km from Kuantan, the capital city of Pahang state, Malaysia. Several industrial enterprises of different sizes are in Pekan, including the defense & security manufacturing division plant (Malaysia's largest military vehicle manufacturer), automotive plants, oil & gas, food, and woodworking industries. The Pekan area is comprised of a massive amount of swamp forest, including the Nenasi, Resak, Rompin, and Endau Swamp Forest in the south-eastern Pahang State, which stretches south from Kuantan to the Pahang-Johor border and extends some 40 km inland from the coast. Several rivers drain the forests in the Pekan area, such as Sungai Endau, Sungai Rompin, Sungai Pahang, Sungai Bebar, and Sungai Merchong River. The lower reaches of the rivers are brackish and acidic in peat areas. Pekan area is mainly covered with various types of soil species, including sedentary, organic clay, and peat, and this area is familiar with several types of agricultural activities such as palm oil, pineapple, and banana plantation, which are the most common plantation in the area, as shown in Fig. 2.

2.2 Site Survey and Sample Method Collection

Three sampling sites were precisely detected by a Garmin GPSMAP 64csx in the Pekan area, namely Kampung Bahru, Kampung Lancang I, and Kampung Lancang II, as shown in Fig. 3 the co-ordination as tabulated in Table 4. Three undisturbed soil specimens were collected from each location involved in the different agricultural activities. A manual sampling method was applied for accumulating peat specimens in a range of 20 - 60 cm depth of the topsoil. The steel measurement scale was used to ensure the depth measurement for the samples began at the top of the soil horizon using a mattock and a stainless-steel shovel. The in-situ undrained shear strength was measured using a hand field vane shear apparatus, while pH was measured on-site by following the soil pH meter. The plant structures such as roots and wood are easily recognizable in the peat soil samples. The specimens were stored in a polyethylene bag to avoid any characterization loss; as shown in Fig. 4, samples were brought back to the laboratory for analysis. Initially, the soil specimens were air-dried and passed through a 2 mm sieve to separate the coarse sediments, pebbles, roots, plant remains other unwanted materials, and subsamples were further ground to pass through a 0.25 mm sieve. Some soil tests such as moisture content, liquid limit, organic content, and degree of humification existed to observe the peat's physical properties.

Table 3 - The peatland distribution worldwide Frolking [48], [49]

Continents	Countries	Total land area(km^2)	Peatland area(km^2)
North America	Canada	9,084,977	1,132,614
	USA	9,161,923	197,841
	Other	6,462,100	8866
	Total	24,709,000	1,339,321
Asia	Russia (Asian part)	9,784,930	1,180,358
	Indonesia	1,811,569	148,331
	Malaysia	328,657	22,398
	China	9,326,410	136,963
	Other	23,327,434	135,132
	Total	44,579,000	1,623,182
Europe	Russia, (European-parts)	6,592,812	185,809
	Sweden	410,335	60,819
	Finland	303,815	71,911
	UK	241,930	22,052
	Ireland	68,883	22,052
	Others	2,562,225	16,575
	Total	2,562,225	171,171
South America	Total	17,840,000	485,832
Africa	Total	30,370,000	187,061
Oceania	Total	7,692,024	68,636
Global	Total	148,647,000	4,232,369

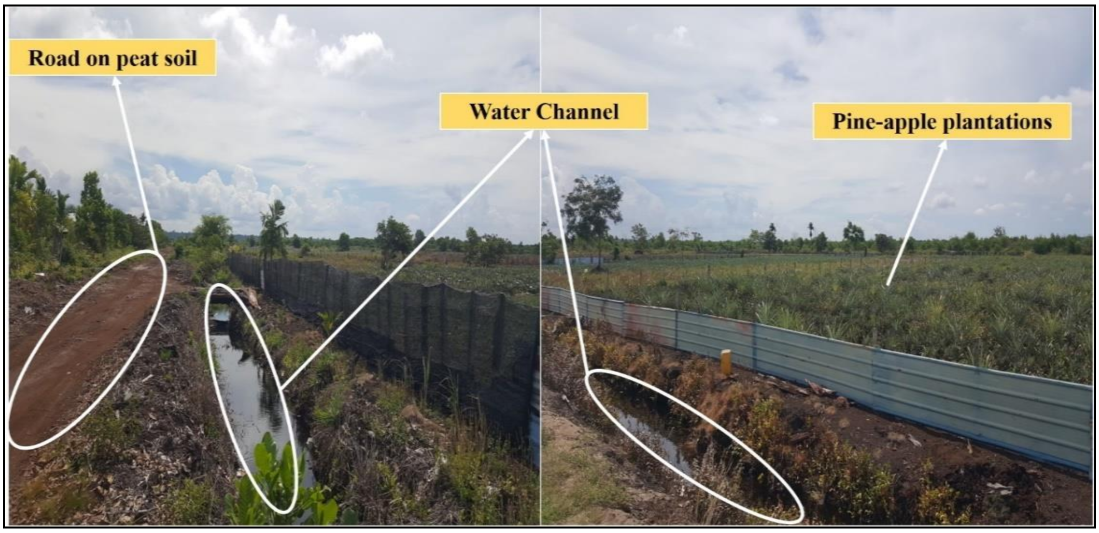

Fig. 2 - The surface topography of Pekan peat soil

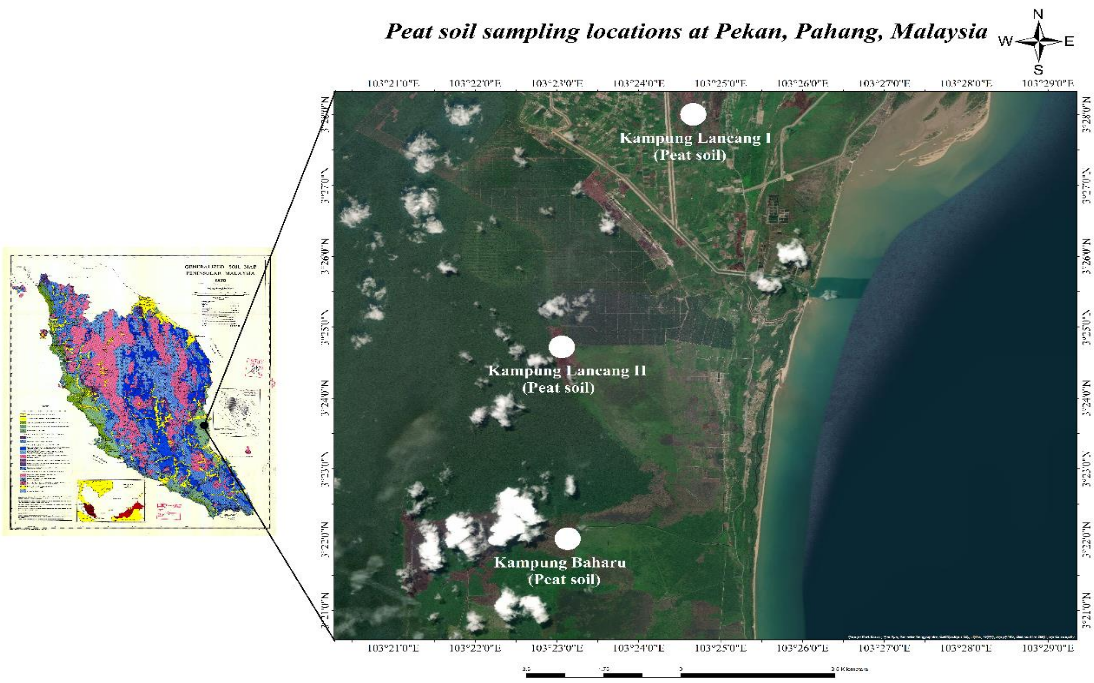

Fig. 3 - Peat sampling locations in (National Soil Maps (EUDASM) Maps Published by Dicetak oleh Direktorat Pemetaan Negara, Malaysia.1970)

Fig. 4 - The peat soil samples collection (polyethylene bag)

Table 4 - The GPS co-ordination of sampling locations

Peat sampling location	GPS Co-ordination
Kampung Bahru	3°24'30. 0" N, 103°41'84. 37" E
Kampung Lancang I	3°24'18. 05" N, 103 °41'08. 25" E
Kampung Lancang II	3°23'49. 05" N, 103°41'51. 39" E

2.3 Physical Properties Analysis

The physical properties test was conducted in the soil mechanics and geotechnics laboratory, University Malaysia Pahang. British Standard has followed all the laboratory tests. Undrained Shear strength (ASTM D2573/D2573M-15) was measured during sampling collection using hand field vane shear apparatus; the American Standard was followed for in-situ undrained shear strength because there is no specific standard available for hand field vane shear strength in British standard. Moisture content (BS 1377: Part 2:1990), liquid limit (BS 1377: Part 2:1990), standard Procter compaction test (BS 1377: Part 4:1990), degree of humification, and organic content (BS 1377: Part 3: 1990) was observed at the laboratory.

3. Results and Discussion

This section focuses on the detailed measurement of physical and chemical properties such as shear strength, moisture content, liquid limit, degree of humification, pH, organic content, maximum dry density, and shear strength of peat soil in the laboratory of the British Standard. The summary of peat soil's physical properties is tabulated in Table 6.

3.1 Shear Strength (kPa)

The shear strength was measured in nine different points at Kampung Bahru, Kampung Lancing I, and Kampung Lancing II for peat soil using a hand field vane shear apparatus during sampling. Kampung Bahru peat's shear strength was observed at 7.5 kPa, Kampung Lancing I was 8.2 kPa, and Kampung Lancing II was 7.2 kPa, as shown in Fig. 5. According to [50], the average shear strength of Malaysian peat is in the range of 3 to 17 kPa.

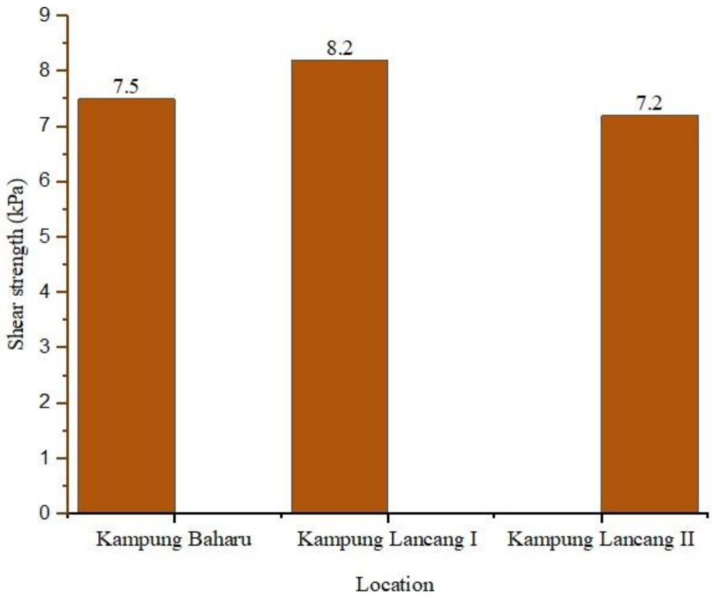

Fig. 5 - The shear strength (kPa) for peat soil

3.2 Moisture Content Test (WN)

The moisture content test was measured to observe the water content in peat soil followed by British standard BS 1377: Part 2:1990 clause 3.2. The results indicated diverse moisture content values for each location because of the fluctuations in groundwater level on-site and undrained forested conditions. Kampung Bahru peat soil's initial moisture content was observed at 601.859, 537.106 % for Kampung Lancing I, and 635.285% for Kampung Lancing II, as shown in Fig. 6 and Table 5. Some previous studies explained that the average moisture content of Malaysian peat soil ranges from 200-2200 % [51], [20], [35].

3.3 Liquid Limit (WL)

The liquid limit was examined for Kampung Bahru peat soil at about 142.434 %, 152.540 % for Kampung Lancang I, and it was observed at 137.638 % of Kampung Lancing II peat soil. Kampung Lancang II peat soil was noticed as weak properties compared to Kampung Bahru and Kampung Lancang I, as shown in Fig. 7, Fig. 8, and Fig. 9. A previous study revealed that the liquid limit for Malaysian peat soil is ranged from 73.00 - 417 % [51], [39].

3.4 Maximum Dry Density and Optimum Moisture Content

The compaction test was conducted for untreated peat to determine the maximum dry density (MDD) ρd (kg/cm3) and optimum moisture content. It was observed that compaction increases the shear strength of the soil. Similarly, three representative samples were taken from each location. The MDD observed for Kampung Bahru peat was 7. 99×10-7 kg/m^3, and Kampung Lancing I MDD was measured at about 6. 68×10-7 kg/m^3 was examined 6. 82×10-7 kg/m^3 for

Kampung lancing II peat soil. Previous studies [41], [35] mentioned that the average maximum dry density for Malaysian peat is in the range of 1.12 × 10-7 kg/m^3 to 8.90 × 10-7 kg/m^3. The optimum moisture content was observed 38.96% for Kampung Baharu, 128.90% for kampung Lancang I, and 68.39% for Kampung Lancang II peat soil. Previous researchers stated that the average liquid limit for Malaysian tropical peat soil ranges from 1.12 to 8.90×10-7 kg/m^3 [35].

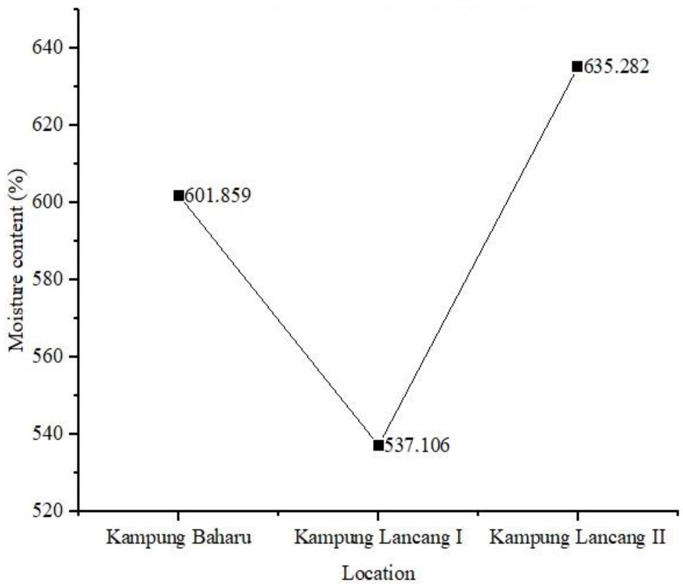

Fig. 6 - The average moisture content of peat soil

Table 5 - The moisture content for KB, KL I, and KL II peat soil comparison with previous research findings

Location	Moisture Content	Value	Reference
Kampung Bahru	601.859	200 to 700%	Mohamad[33]
Kampung Lancing I	537.106	480.61%	Adnan [35]
Kampung Lancing II	635.285	200 to 2200%	Adnan [35]

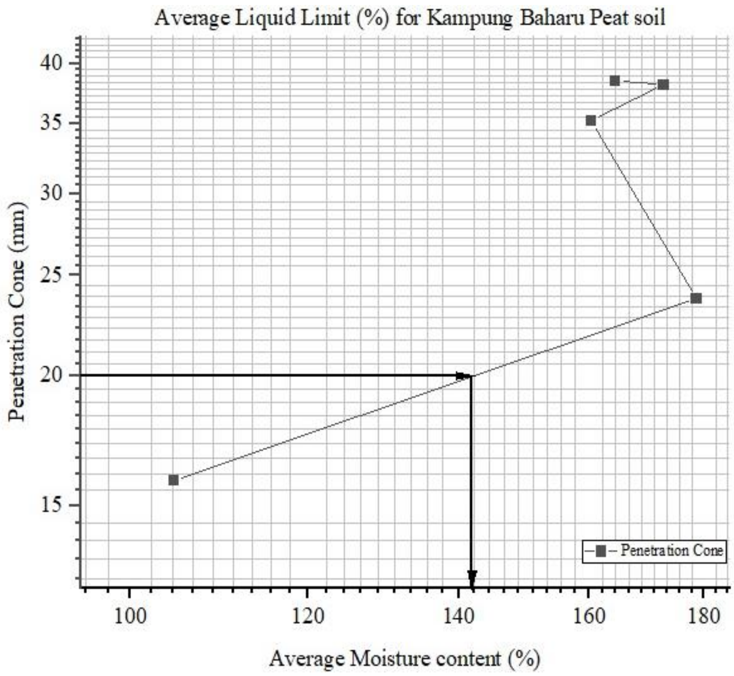

Fig. 7 - The liquid limit for Kampung Baharu peat soil

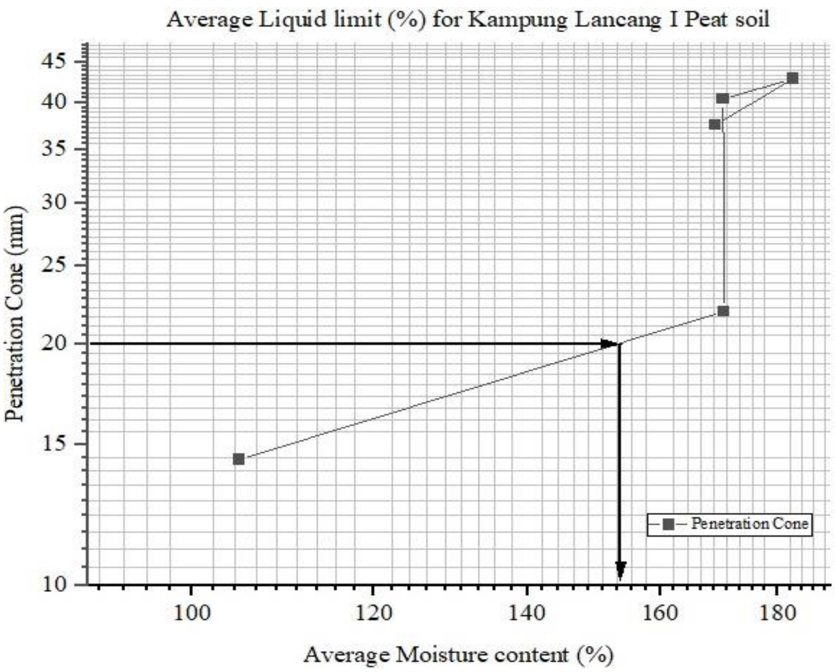

Fig. 8 - The liquid limit for Kampung Lancang I peat soil

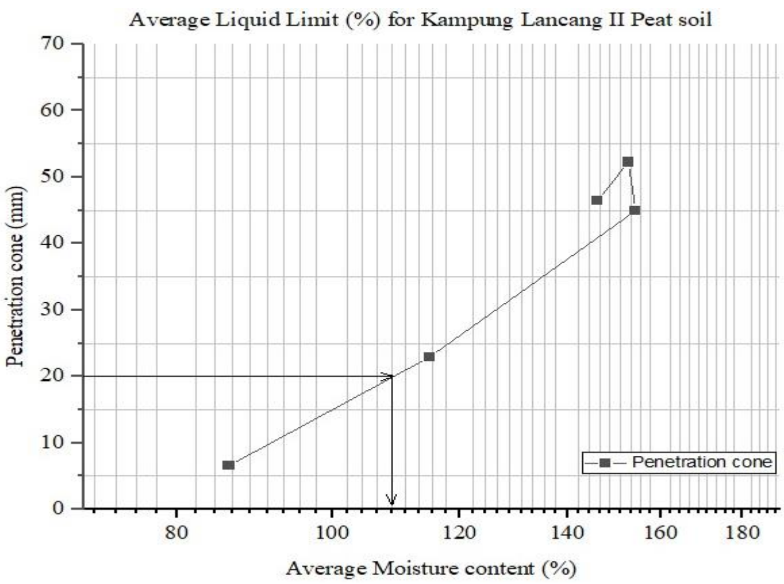

Fig. 9 - The liquid limit for Kampung Lancang II peat soil

3.5 Degree of Humification

The degree of humification for the Pekan peat soil was observed during sampling collection, where when it was compared to the humification chart, it was marked H5 for Kampung Bahru peat soil, H7 for Kampung Lancang I, and for Kampung Lancang II it was detected H6. In contrast, according to [52], the degree of humification for Parit Nipah peat soil is H5, and [33] revealed the degree of humification for Penor peat soil is H6.

3.6 Organic Content (OC)

The organic content was determined for peat soil followed by 'loss on ignition' the peat soil sample was heated to 400°C where the organic content for Kampung Baharu peat soil was measured 97.8 %, Kampung Lancang I was 95.88 %, and it was recorded 98.48 % for Kampung Lancang II peat soil as shown in Fig. 10, which was illustrated as pure peat soil. According to previous research, Malaysian soil's average organic content is in the range of 25-99 % [53].

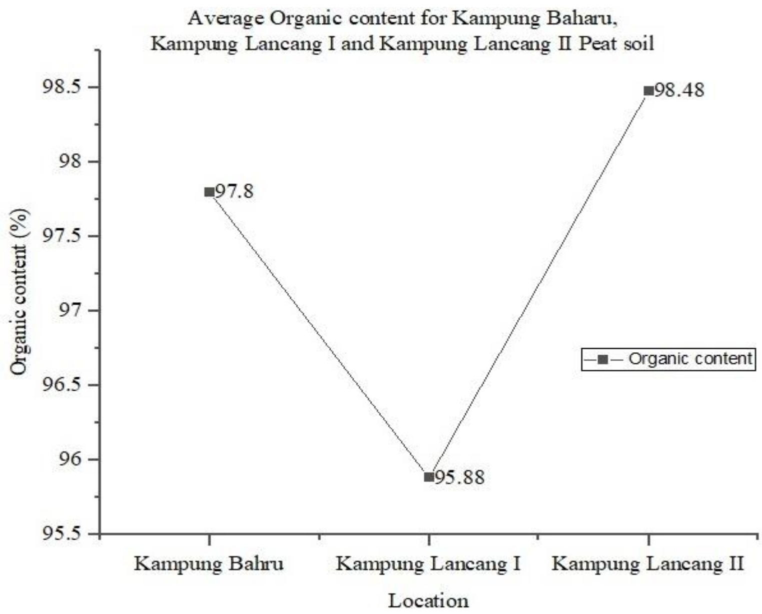

Fig. 10 - The organic content for Kampung Bahru, Kampung Lancang I, and Kampung Lancang II peat soil

4. Conclusions

This paper presented the physical properties of untreated tropical peat soil from the Pekan district, and for better understanding, its characteristics were compared with observed peat soil properties. Based on the concluded results following conclusions were drawn from this study.

(a) The peat soil has high natural moisture content because of the undrained forested conditions. The weather condition due to changes in rainfall, precipitation, and temperature is directly proportional to the soil saturation, which may cause fluctuation in the water table. A large wide-ratio has been observed, making the peat soil very soft, compressible, and sensitive from a construction perspective.
(b) The shear strength of peat soil is not suitable for construction, especially for roads and buildings; it's essential to enhance its share strength for any construction.
(c) The formation of ground fiber content is increasing due to continuous agriculture activities in this area. The dead plants and crops contribute to decomposing materials to form peat organic matter.
(d) The organic content of Malaysia peat soil ranges from 76 to 99%, and In the Pekan area, the organic content was measured high compared to other peatland sites in Malaysia due to agricultural activities.
(e) This study's findings would be convenient for the construction industry, and despite this, further study is highly recommended to strengthen its weak properties, which may lead it to construction stability.

Table 6 - The summary of the physical and chemical properties of peat soil

Properties	Kampung Bahru	Kampung Lancing I	Kampung Lancing II
Shear strength *(kPa)*	7.5	8.2	7.2
Moisture content *(%)*	601.859	537.106	635.285
Organic content *(%)*	97.8	95.88	98.48
Liquid Limit *(%)*	142.434	152.540	137.638
Maximum Dry Density *(kg/m^3)*	7.99×10^{-7}	6.68×10^{-7}	6.82×10^{-7}
Optimum Moisture Content *(%)*	88.96	128.90	68.39
Degree of Humification	H5	H7	H6

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