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An Overview on Japan and Malaysia Peat Relating to Geotechnical Characteristic

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Abstract: Peat deposits distribution is extensive and can be found in many countries throughout the world when the conditions are favorable for their accumulation and formation at different climatic zones. These deposits represent the extreme form of soft soil and subject to instability and enormous primary as well as long-term settlement even when subjected to moderate load. Access to these superficial deposits is usually very difficult as the water table will be at near or above the ground surface. To sum up, peat is considered as unsuitable soils for supporting foundations or any construction works in its natural state. This paper presents some review of peat soil from Japan and Malaysia pertaining to geotechnical properties in order to develop and expand an understanding about tropical peats for future studies. The parameters studied were the moisture content, loss on ignition, unit weight, specific gravity (G_s), fiber contents, acidity, liquid limit (L_L), plastic limit (P_L), plastic index (P_I) and shear strength. Overall, Hokkaido peat that had been studied has many similarities of peat properties with Malaysia peat especially in West region including Johor peat.

Keywords: Peat soil, geotechnical properties, Malaysia and Japan peat

1. Introduction

Peat deposits distribution is extensive and can be found in many countries throughout the world when the conditions are favorable for their accumulation and formation at different climatic zones from arctic to tropical in both northern and southern hemispheres [1-4]. The identification of peat is very important because they are much weaker than mineral (inorganic) soils. As such they do not provide suitable supports for most engineering works. Peat and organic soil represent the extreme form of soft soil and subject to instability and enormous primary as well as long-term settlement even when subjected to moderate load [5]. These materials can also change chemically and biologically over time. For instance, humification of organic matter that continues may change the mechanical properties of soil such as compressibility, shear strength and hydraulic conductivity. Dropping of ground water may cause shrinking and oxidation of peat leading to humification with consequent increase in permeability and compressibility [6]. Besides, these soils are problematic as they are very highly compressible and are of very low shear strength. Numerous construction techniques have been carried out to support embankments over peat soils without risking bearing failures but settlement of these embankments remains extremely large and continues for many years. In addition, stability problems during construction such as localized bearing failures and slip failures need to be considered [2]. Access to these superficial deposits is usually very difficult as the water table will be at near or above the ground surface. Undoubtedly, this is a consequence of the tendency to avoid either the construction and building on this land, or when this is not possible, to just remove, replace or supersede those in certain circumstances can lead to possibly uneconomical design and construction alternative [7]. Peat soil bearing capacity is very low and seems to be influenced by the water table and the presence of wood chips under the ground [8,9]. To sum up, peat is considered as unsuitable soils for supporting foundations or any construction works in its natural state.

This paper presents some review of peat soil from Japan and Malaysia pertaining to geotechnical properties in order to develop and expand an understanding about tropical peat for future studies.

2. Definition and classification

Peat definitions and classifications are different between countries. Some such names are bogs, moors, muskeg, mire, tropical swamp forests and fens. These names help characterize the peat by its differences resulting from the effect of climate and type of plant materials that constitute the peat. Geotechnically, peat soils described as soil that having an organic content greater than 75%. In Japan, peat generally includes soil with more than 20% organic contents because of their engineering properties [10]. Most of these soils are controlled by its quantity and quality of organic matter contents, and physical properties. However, the definition and description of peat between soil scientists and geotechnical engineers are different. Scientists have described as peat soil with organic matter content greater than 25%. Current classification systems for peat and organic soils use organic and ash content as the sole

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parameter in classification [11-14]. However, Loughlin and Lehane [15] observed that a classification system based observed that a classification system based on organic content and ash content was not sufficient. Other factors such as natural water content, structure, degree of humidification, nature of organic material and also specific gravity also need to be considered. United Soil Classification System (USCS), adopted by the American Society for Material Testing (ASTM) defines organic soils as a separate soil class in the standard classification of soils for engineering as shown in Table 1.

Table 1 Classification of peat based on ASTM standards

Fiber content (ASTM D1997)	Fibric peat- fibers > 67% Hemic peat- 33% < fibers < 67% fibers Sapric peat- fibers < 33%
Ash content (ASTM D2974)	High ash peat- ash > 15% Medium ash peat- 5% < ash < 15% ash Low ash peat- ash < 5%
Acidity (ASTM D2976)	Highly acidic peat- pH < 4.5 Moderate acidic peat- 4.5 < pH < 5.5 Slightly acidic peat- 5.5 < pH < 7.0 Basic peat- pH ≥ 7.0

In Malaysia, classification of peat and organic soils is based on the British Standard 5930:1981. Nevertheless, this classification has been upgraded by Public Work Malaysia and Jarret [5] to make this system more clear and suitable to the Malaysian situation. The Malaysian Soil Classification Systems (MSCS) showed in Table 2 introduced the degree of humidification by Von Post scale as the second important parameter to be considered after organic content [12]. Von Post scale is a classification system which is based on a number of factors such as botanical composition, degree of humification, and the color of peat water after squeezing. In this classification system, there are ten degrees of decomposition ranging from H1 (very fibrous) to H10 (very few fibers), which represent the state of decomposition/decay of the organic plant remains. Higher the number in von Post scale, higher is the degree of decomposition. The degree of decomposition is determined to be ten degree based on the appearance of soil water coming out upon squeezing the soil in the hand. Peat near the surface fall into the H3 and H4 categories, but with increasing depth it would be classified as H5 to H7 [16]. In Peninsular Malaysia, the ash content and organic content of peat are at an average of 3.55 and 96.45% respectively. These show that peat has very high content of organic matter and indicate the loss of ignition value exceeding 90% [8,17].

In technical term of geotechnology edited by Japanese Society of Soil Mechanics and Foundation Engineering, soil with more than 5% organic contents classified as organic soils and with more 50% as highly organic soils and generally called peat in Japanese soil science particularly by Hokkaido Agriculture Experiment Station. They classify the soil with 20-50% of organic contents as sub-peat. Between the range 5% to 50% organic contents, the soils has classified as low organic soils such as Kuroboku soil [10]. Study conducted by Noto [10] on engineering characteristic of Hokkaido peat, the organic content of peat are between 20 and 98%. These show that Hokkaido peat is similar to Malaysian peat with very high content of loss of ignition value.

Table 2 Malaysian Soil Classification Systems (MSCS) for Organic and Peat [5]

Soil group	Organic content	Soil Symbol	Degree of Humidification	Subgroup name	Field Identification
Peat	> 75%	Pt	H1-H3	Fibric or Fibrous Peat	Dark brown to black in color. Material has low density so seems light. Majority of mass is organic so if fibrous the whole mass will be recognized plant remains. More likely to smell strongly if highly humidified
			H4-H6	Hemic or moderately decomposed peat	
			H7-H10	Sapric or amorphous peat	

3. Formation and distribution

Jarret [18] described peat as naturally occurring, highly organic substance derived primarily from plant materials. Peat is formed when the rate of accumulation of organic matter is greater than the rate of decay. Peat actually represents an accumulation of the disintegrated plant remains, which have been preserved under condition of incomplete aeration and high water content. It accumulation wherever the conditions are suitable, that is, in areas with excess rainfall and the ground are poorly drained, irrespective of latitude or altitude. Nonetheless, peat deposits tend to be more common in those regions with comparatively cool wet climate. Physico-chemical and biochemical process cause this organic material to remain in a state of preservation over a long period of time. In other words, waterlogged poorly drained condition, not only favor the growth of a particular type of vegetation but also help preserve the plant remains [6].

Peat in Japan, in many cases is basin peat, formed when lakes and marshes become filled with dead plants growing around them and then turn into land. This type of peat is characterized by the spongy formation of plant fiber. In the peatland of Hokkaido, peat commonly accumulates to a thickness of three to five meters on the ground surface, while the soft clay layer underlying is the peat is often over 20 meters thick. In some areas, a sand layer exists between the peat and the clay layers. The rate of deposition of peat depends on humidity and weather conditions [10,19].

Huat [19] observed the depths for peat deposits in Malaysia were varying from 1m to 20m. The colour of peat soils in Malaysia is generally dark reddish brown to black. It consists of loose partly decomposed leaves, branches, twigs and tree trunks with a low mineral content [11]. The ground water table in these areas is always high and occurs at or near the surface [20]. According to Jamil [21] where soil with peat depth of <1.0 m, 1.0 – 1.5 m, 1.5 – 3.0 m, and >3.0 m is classified as shallow, moderate, deep and very deep peat. In its drained state, the peat will transform to a compact soil mass consisting of partially large wood fragments and tree trunks embedded in it. Drainage influences the degree of decomposition, shrinkage and consolidation behaviour of the soil [11].

The peat land consists of nearly 5 to 8% of the earth land surface and nearly 60% of the wetland of the world is peat [1]. While the areas occupied by the tropical peat land is about 30 million hectares and two third of that are in South East Asia. These soils are found in many countries throughout the world. In the US, peat is found in 42 states, with a total acreage of 30 million hectares. Canada and Russia are the two countries with a large area of peat, 170 and 150 million hectares respectively. In term of country land area, Finland recorded the highest percentage with 33.5% while Malaysia was ranked 10th in the world with 8% and Japan ranked 26th with 0.5% [3].

Fig. 1 Peat land distribution in West (left) and East Malaysia (right)

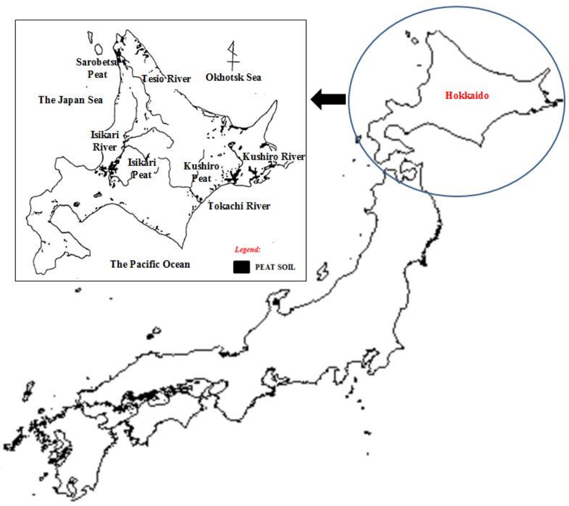

Fig. 2 Distribution of peat land in Hokkaido

In Malaysia, there is approximately 26,000 km^2 of peat that accounting for about 8% of the country's land area (Fig. 1) [3,22]. Among these lands, 6,300 hectares of the peat lands are found in Pontian, Batu Pahat and Muar in West Johore [23]. Peat forests, once found extensively in the district of Pontian, have been converted to agriculture for oil palm, pineapple and other food crops [24]. The state that covers the largest area of peat land in Malaysia is Sarawak which is about 13% of the state area or 1.66 million hectares with 89% of these areas are more than 1m in depth [25].

In Japan, peat is widely distributed through Hokkaido especially along the lower reaches of the Ishikari, Kushiro and Tashio Rivers with approximately 2,000 km^2 which equals to 6% of the flat area of the island (Fig. 2) [10].

4. Geotechnical characteristic review

The physical study of peat on geotechnical characteristics has been done by several researchers especially geotechnical engineers and academician to ensure that any construction on peat are safe. As mentioned earlier, this paper presents some review of peat soil from Japan and Malaysia pertaining to geotechnical properties. The parameters studied were the moisture content, loss on ignition, unit weight, specific gravity (G_s), fiber contents, acidity, liquid limit (L_L), plastic limit (P_L), plastic index (P_I) and shear strength as shown in Table 3.

One of the important and most variable properties of peat is its water content. The value of water content depends on the origin, degree of decomposition and the chemical composition of peat. Naturally, peat has very high natural water content due to its natural water-holding capacity. The high natural water holding capacity is because of the soil structure characterized by organic coarse particles (fibers) which can hold a considerable amount of water since the soil fibers are very loose and hollow. The high water content is also because peat has low bulk density and low bearing capacity as results of high buoyancy and high pore volume [16]. Ajlouni [26] emphasized that the water content of peat may range from 200 to 2000% which is quite different from that for clay and silt deposits which rarely exceed 200%. The results in Table 3 revealed that Malaysia and Japan peat soil varies from different geographical locations when natural water content is consent. This is due to the influence of different agricultural background of the area and rainfall intensity [12].

Natural water contents and organic contents for tested peat sample from Hokkaido were determined by author by drying a peat or organic soil sample at 105°. Ash content was determined by igniting the oven-dried sample in a muffle furnace at 440°C about 7 hours (until no change in mass). The ash content is expressed as a percentage of the mass of the oven-dried sample. Organic matter is determined by subtracting percent ash content from one hundred. The results for water and organic contents as calculated were 580% and 83.21% respectively. These values are consistent with studies conducted by Noto [10] and Hamamoto [27] which revealed that Hokkaido peat have range of water content 110% to 1600% while organic content range 20% to 98%. In Malaysia, these parameters are higher than Japan peat with water contents accounted to 200% and can reach to 2200% whereas organic content range 50% to 98%.

The bulk density (unit weight) of peat is low and variable compared to mineral soils. The average bulk density of fibrous peat is around the unit weight of water (9.81kN/m^3). Range of 8 to 12kN/m^3 is common for unit weight of peat in Malaysia [19]. In Japan, range of unit-

Table 3 Geotechnical engineering characteristic of peat land in Malaysia and Japan

Properties		Japan			Malaysia			
			Hokkaido		West	East	Johore	Pontian
Natural water content, %		580	115-1570	283-1211	200-700	200-2207	230-500	659
Loss on ignition	Ash content, %	16.79	2-80	3.2-51.3	3-35	5-50	4-20	1.5
	Organic content , %	83.21	20-98	48.7-96.8	65-97	50-95	80-96	98.5
Bulk unit weight (kN/m^3)		12.5	7.1-19.7	7.3-13.03	8.3-11.5	8-12	7-11	12.3
Specific gravity, G_s		1.67	1.04-2.63	1.37-2.63	1.38-1.7	1.07-1.63	1.48-1.8	1.44
Fiber content, %		41	42-86.9	42-86.9	31-77	-	-	49
Acidity ,pH		5.46	-	-	-	3-7.2	-	3.63
Atterberg limit, %	Liquid Limit	375	-	-	190-360	210-550	220-250	380
	Plastic Limit	-	-	-	100-200	125-297	-	-
	Plastic Index	-	-	-	90-160	85-297	-	-
Undrained shear strength, *kPa*		13.20	5-40	-	8-17	8-10	7-11	-
References		Authors	[10]	[27]	[19]	[19]	[36]	[35]

weight is between 7 and $20kN/m^3$. Unit weight of the peat will be affected by the water content of peat; as the water content increase, the unit weight will show a sharp reduction. When water content about 500%, the unit weight ranges from 10 to $13kN/m^3$ [5,28]. This fact proved by author when obtaining the unit weight of Hokkaido peat with $12.5kN/m^3$ at 580% water contents. Similar with the specific gravity, the bulk density of peat depends on the structure and degree of decomposition. Bulk density of peat is usually smaller than the mineral soils due to the lower specific gravity of the solids found and the higher water holding capacity in peat and the presence of gas [29].

Specific gravity of peat is greatly affected by its composition and percentage of inorganic component. It is related to the degree of decomposition and mineral content of peat. Higher specific gravity indicates a higher degree of decomposition and higher mineral content. For peat with an organic content of 75% and greater, the specific gravity is in the range from 1.3 to 1.8 with an average of 1.5 [26,30]. Specific gravity for tested peat was recorded 1.67 which is mean this soil have fairly high degree of decomposition and mineral content. In fact, above 600% water content, both the specific gravity and water content do not greatly influence bulk density. On the other hand, low influence is attributed to higher degree of saturation or gas content [31,32]. Peats frequently are not saturated and may be buoyant under water due to the presence of gas. Except at low water contents (less than 500%) with high mineral contents, the average bulk density of peat often is slightly lower than that of water.

In fiber content test, calculated fiber content is 41% which is categorized as hemic peat according to classification of peat by ASTM as shown in Table 1. With 16.79% of ash contents, studied peat is classified in high ash group. Compared with fibrous peat deposits, sapric peat deposits are likely to exist at lower void ratios and display lower permeability, lower compressibility, a lower friction angle and a higher coefficient of earth pressure at rest. Hemic peat have properties intermediate between fibrous and sapric peats [16]. In pH test, average pH of soils is quite large with 5.46 compared to Malaysia peat with range of 3 to 7. This means Hokkaido peat are categorized as lightly acidic peat. It appears that organic acids mixed with soil and cement that produce a pH lower than 9 in the pore solution, prevent the development of the cementing products because the pH is too low to allow secondary mineral formation [33].

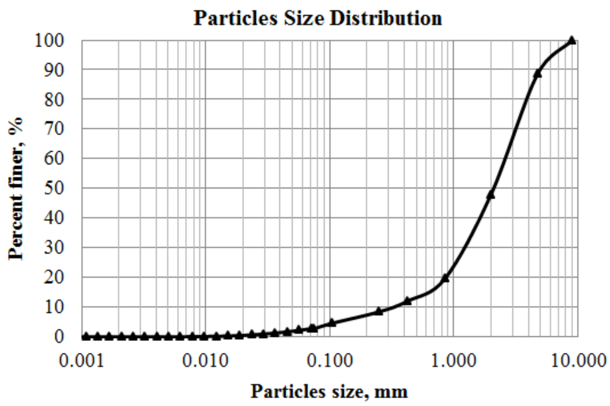

Fig. 3 Graph of Particle Size between 4.75 mm and 75µm

The peat tested in this study often produce clods. The particle size distribution curves for the soils were obtained by dry sieve analysis. In addition to the normal sieve test method, the soil fraction finer than 75µm was analyzed using a diffraction laser method (SALD) which is interpreted as one graph in Fig. 3. As can be seen, Hokkaido peat consists broadly of fine size base on Unified Soil Classification System (USCS) gradation. On average, 90% of the soil is finer than 4.75mm, and 2% is finer than 75µm. The coefficient of uniformity, (C_u) is 9.3, and the average coefficient of gradation (C_g) is 1.71. Obtained pattern of Hokkaido peat particle size distribution is quite similar with the West Malaysia peat conducted by Kalantari [34].

For liquid limit and plastic limit value, Malaysia peat varies from 190% to 550% and 100% to 300% respectively while the studied peat gave the results 375%. Fig. 4 shows the graph of Hokkaido peat analysis for liquid limit determination. Japanese Geotechnical Society (JGS 0142-2000) describes the determination of liquid limit using the fall- cone method. JGS method suggests be careful roll soil samples into threads until it become thinner and eventually break at about 3 mm diameter.

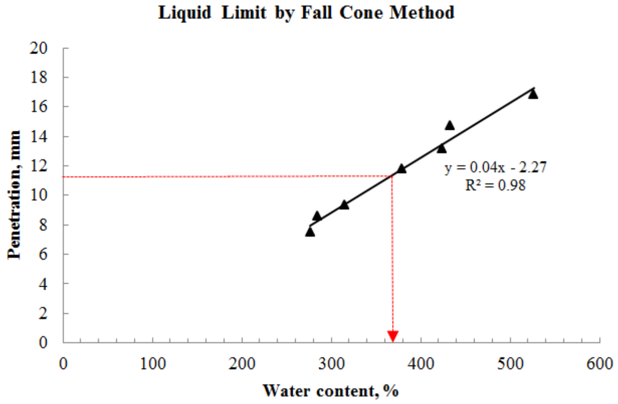

Fig. 4 Graph of Liquid Limit Analysis

Author faces the problem in order to get the plastic limit of tested peat by this method. Peat soil can be moulded to this shape but failure occurred due to peat not behaving as a plastic material [35]. Bee-Lin Tang [35] also proved hemic peat in her study gave almost zero plastic limit by adopting Feng method. Zainorabidin and Ismail [36] have previously encountered problems when attempting to determine the plastic limit of Malaysian hemic peat. The presence of the fibres in peat makes the process of determining the Atterberg limits difficult and less accurate. According to Hobbs [32], it was impossible to carry out plastic limits tests on pure bog peat. On the other hand, even if the peat is highly humidified there was little point in performing plastic limit testing on peat soils since the deduced plasticity index gives little indication of their character. Hokkaido peat analysis for Unconfined Compression Strength (UCS) shows the peak was not obtained until 20% of axial strains. Hence, the maximum value of UCS was taken at 15% of strain which is equal to 26.4kPa. From this result, undrained shear strength was equal to 13.2kPa. These values indicate that Hokkaido peat soils are very soft. According to International Building Code (IBC-2009) any profile with more than 3 m of soil, plasticity index, PI>20, Moisture content, $\omega \geq 40\%$ and average undrained shear strength S_U <24kPa are considered as soft soil. Overall, Hokkaido peat has many similarities of soil properties with Malaysia peat especially in West region including Johor peat.

5. Further research

Due to population and economic growth in Southeast Asia like Malaysia and Japan, land use activities perceived increased dramatically. As a result, good land for infrastructure development has decreased and become a serious problem in the future. The vastness of peat land coverage and its occurrence close to or within population centres and existing cropped areas means some form of infrastructure development has to be carried out in these areas. These would include road crossings, in some instances, housing development that encroaches into peat land areas as available land become more and more scarce. To stimulate agriculture development for instance, basic civil engineering structures are required. These would include irrigation, drainage, water supply, roads, farm building, etc. Conventionally, the normal practice is to avoid such soils, or excavate (cut and fill or replacement method) or drive pile through them [19]. However due to dearth of suitable land for infrastructure development and agriculture, evasion of construction on poor lands such as organic and peat land is no longer option anymore. Replacement method will make large scale disposal of peaty soils in unacceptable amount in future [24]. Disposal of poor quality surplus material can be regarded as one of the most significant environmental problems in construction [37]. Structures on peat that suspended on piles normally give deposition effect to surrounding ground [6]. Currently, the utilization of peat land in Malaysia is quite low although construction on marginal land such as peat has become increasingly necessary for economic reasons. Engineers are reluctant to construct on peat because of difficulty to access the site and other problems related to unique characteristics of peat. Thus, not much research has been focused on the development of soil improvement method for construction on peat soil [38].

In order to overcome these problems, there has therefore been a need to develop a functional, economical, and more environmentally friendly method for improving mud and peat [39]. Soil improvement plays a vital role in geotechnical engineering because it is the only way to stabilize and enhance the properties of soils. Most of the time, the improvement is focused on modifying and stabilizing the soil. This is because stabilization of soil is one of the most important criteria that should be considered for construction on soft soil. Stability of ground will affect the stability of the structure above it. If structures are placed without any proper ground improvement to provide adequate stability to the ground, failure of structures may happen and this will cause death, loss of money and energy. Hence, a proper ground improvement work is essential before starting construction works over peat [40]. In countries like Malaysia, peat and organic soils are found in abundance. Suitable Geotechnical design parameters and construction techniques needed to be found for this type of ground condition. It is therefore necessary to expand our knowledge on the engineering or mechanical properties of the peat and organic soils [6,7].

In scope of economical, environmentally and friendly method in stabilizing peat, mass stabilization technique perceived meets these requirements [39]. Further research will be carried out at the Kyushu University to determine and identify the peat improvement by laboratory mass stabilization based on the strength and deformation characteristics. In this study, Ordinary Portland Cement

(OPC) will be used as a stabilizer (binder) while sugarcane bagasse ash (SCBA) as a cement replacement and also as pozzolanic materials. The research main target is to utilize an agriculture waste namely SCBA in peat stabilization by OPC in order to reduce cost and pollution (caused by cement consumption and ash waste).

6. Conclusion

In conclusion, this paper has given properties overview of Japan and Malaysian peat relating to geotechnical properties. Overall, Hokkaido peat that had been studied has many similarities of peat properties with Malaysia peat especially in West region including Johor peat. These similarities display in Table 3 which is shows the whole comparison between Malaysia and Hokkaido peat. Studied peat can be categorized as hemic with high ash and lightly acidic peat. This research results also lead to a better understanding of the performance of Japan and Malaysia peat for better geotechnical design in future.

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