Overview of the Sustainable Uses of Peat Soil in Malaysia with Some Relevant Geotechnical Assessments

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Abstract: Peat soil is an important ecosystem that provides a significant contribution to the global climate stability. In Malaysia, peat soils are considered as a soil with little economic benefit, apart from it being used for agricultural activity. The total world coverage of peat soil is about thirty million hectares with Canada and Russia having the largest distribution of peat (Zainorabiddin,2010). More than sixty percent of the world's tropical peat lands are found in South-East Asia (Lette,2006). Most notable are the large peat land on the islands of Borneo (belonging to Indonesia, Malaysia and Brunei) and Sumatra (Indonesia). However, there are also significant occurrences in other parts of Indonesia, Malaysia, Vietnam, Thailand and the Philippines. The main contributory functions and benefits of peat soil are within the engineering disciplines of hydrology, agriculture, social-economics, biodiversity habitats and carbon sequestration. Peat was used in temperate climates (especially in Finland, Ireland, Sweden and UK) as a fuel to generate electricity and heat. Therefore peat can be considered as a renewable energy source but this will be very detrimental to the market of genuine renewables. The western coastal lowlands of Malaysia (such as Kukup) are mangroves that represent the initiation of peat soil formation. Such areas provide the natural habitat of mangrove forests. It also fixes more carbon from the atmosphere than is released and approximately one-quarter of the carbon stored in land plants and soils. On the other hand, peat is one of the problematic or challenging foundation soil of poor quality due to it's very high water content, high compressibility and low shear strength. Peat consists of decomposed plant fragments and the unfavourable characteristics of peat soil deposits make them unsuitable for making sustainable infrastructure development for varied engineering projects. This paper therefore gives an overview of the pros and cons debate of sustainability aspects and in the light of the challenges it poses to infrastructure development in Malaysia.

Keywords: fuel, global climate, mangrove, renewable, sustainable.

1. Introduction

Peat is brownish-black in colour and is formed by decomposed organic matter that have accumulated over thousands of years, with lack of oxygen and under waterlogged conditions. These promote its formation. The strict definition of peat is that it is a soil containing at least 65% organic matter [1-5].

Tropical peat lands can be found throughout the world and are usually found in the river valleys and estuaries. Peat swamp occurs in a few areas in Africa and parts of central America, but more than 60 per cent of the world's tropical peat lands are found in South-East Asia. Most notable of these are the large peat swamp forests on the islands of Borneo (belonging to Indonesia, Malaysia and Brunei Darussalam) (Figs 1) [6]. Based on the global chart of total peat deposit around the world, Malaysia is the 9th country with the highest total area of peat soil. The total area of peat soil in Malaysia is about 2.6 million hectares (26,000 km^2), of which about 13 % are in the peninsular Malaysia, over 80 % in Sarawak and about 5 % in Sabah [6-7]. Though this is a relatively large area, it appears smaller when compared with 1,500,000 km^2 in Canada, 170,000 km^2 in Indonesia, and 42,000 km^2 in China.

Table 1 Division of peat area distinguished by countries [8]

Country	Area (km^2)	Country	Area (km^2)
Canada	1,500,000	Germany	16,000
U.S.S.R (theformer)	1,500,000	Brazil	15,000
United States	600,000	Ireland	14,000
Indonesia	170,000	Uganda	14,000
Finland	100,000	Poland	13,000
Sweden	70,000	Falklands	12,000
China	42,000	Chile	11,000
Norway	30,000	Zambia	11,000
Malaysia	25,000	26 other countries	220 to 10,000

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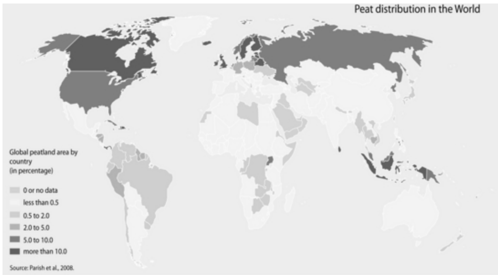


Fig. 1 Peat distribution in the World.

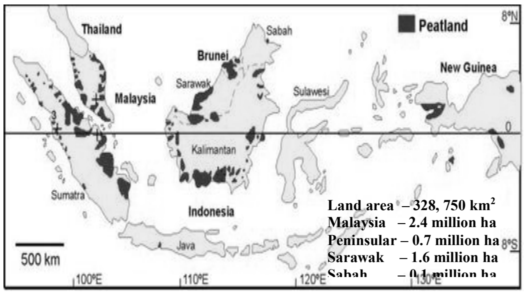


Fig. 2 Distribution of peatlands in SE Asia. [9]

2. Importance of Peatlands

In Malaysian peat lands play an important role and provide a wide range of valuable goods and services. In the beginning peat was uses for household heating and for cooking but the most important use of peat is as a fuel and energy generation. In some county, peat has even been the dominating fuel. Most of the country use peat for energy use comes from peat briquettes. According to Schilstra [10] if peat is milled and compressed at high temperatures it can be pressed into briquettes with user-friendly and predictable burning properties along with a smokeless combustion. These peat briquettes are popular in households that require a fast and readily available fuel for occasional use or in cities where non-smokeless coal are banned. The energy content is lower than brown coal and it needs to be dried before combustion to reduce the water content. An advantage of burning peat together with wood and biomass is that peat reduces ash problems associated with combustion of normal wood fuel.

For agricultural and gardening purposes peat is used as a soil improvement material. By adding milled peat to the soil it is possible to make it better since the peat adds nutrients and retains moisture, thus making the soil more optimal for growing plants. Peat blocks are also used in gardens for creating the foundations for elevated flower arrangements. Peat moss is a good soil conditioner and it assists in loosening clay soils and increase moisture retention in sandy soils. Peat containers for plants and tree seedlings are commonly used in gardens. Peat has also been used as an isolation material for construction due to the low thermal conductivity. Ireland and many other places suffer from lack of major forests and had to use other construction materials. Peat was then used as an isolating layer between the outer wall and the inner wall or as covering material on the roof. Peat fire also gives a very distinct smell and flavor that is used in several whiskey distilleries for obtaining unique properties.

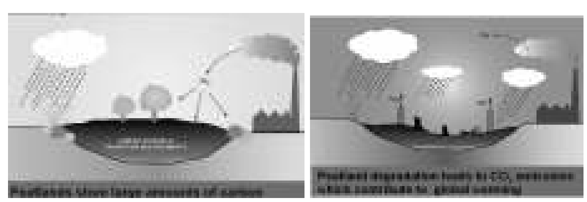
The healthy peatlands of Malaysia provides an environmental benefit. Table 2 below lists some of the benefits from peatlands :

Table 2 Benefit of Peat lands [11]

Grouping	Benefit
Direct uses (goods)	Forestry, agriculture, plant gathering, wildlife capture, fish capture, tourism/recreation, water supply
Functions (services)	Water storage/retention, carbon storage, flood mitigation, nutrient, and toxicant removal.
Attributes	Biological diversity, cultural/spiritual value, historical value, aesthetic value

a. Carbon Sequestration

Recognition of this function has gained in importance in recent years due to the implication of raised CO^2 levels in contributing to global warming. Peatlands have the potential to be a natural solution to reducing greenhouse gas emissions. Peats hold a vast stock of carbon in the soils and can add more by sequestering carbon from the atmosphere. They are one of the few ecosystems which, in their natural state, accumulate carbon. But this natural carbon capture and storage ability can only happen if peatland habitats are healthy and functioning. To get to that state many areas of degraded and damaged peatland, which are currently losing carbon, need to be restored. Minimising peat excavation will reduce these potential carbon losses and consequently reduce the carbon payback period associated with developments on peat. When disturbed either by drainage and burning or both, carbon accumulated over centuries or millennia is rapidly released to the atmosphere contributing to the greenhouse effect and climate change.Estimates suggest that 5,800 tonnes of carbon per hectare can be stored in a 10-metre deep peat swamp compared to 300-500 tonnes per hectare for other types of tropical forest.



(a) (b)

Fig. 3(a) Figure showing that large amounts of carbon can be stored both in the peat and the living biomass in intact peatlands. They also accumulate carbon. (b) When peatlands are degraded, not only is the huge carbon store lost, but also the ability to sequester carbon. Source: Wetlands International.

b. Biodiversity habitats

According to Jean Carter [12] the western coastal lowlands of Malaysia, in common with the opposite shores of Sumatra, are built up of an accumulation of post-Quaternary alluvial clays, and therefore provide the natural habitat of mangrove forests. The Malacca straits are part of the shallow sea and the deepest channel lying between Pulau Kukup and Karimun Island. Figs 4 below shows the cross section of forest type.

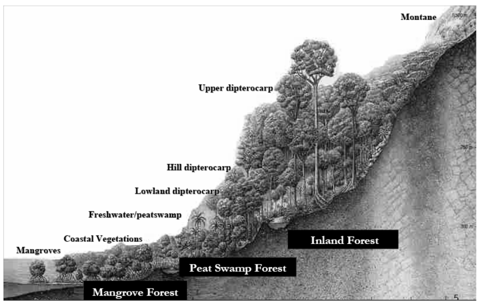


Fig. 4 Cross section of forest type [13]

TanjungPiai and Kukup are prominent mangrove retreats in the district of Pontian, Johor, Malaysia. Tanjung Piai is significant place as it is the southernmost point of the Asian Continent while Kukup is unique due to its informal coastal on-stilt community settlement. Tanjung Piai and Kukup are mainly for tourism and mostly guided by mangrove conservation program, thus the development is more of complimentary to the natural setting placing more emphasis towards mangrove ecology whilst blending well with the surrounding villages. Mangroves are important for:

Grouping	Benefit
Shoreline protection	Mangroves stabilise shorelines, prevent coastal erosion and act as a buffer against storm surges and strong winds
Coastal fisheries	Mangroves provide feeding, breeding and nursery ground for many commercially important fish, prawns, crabs and shellfish.
Biodiversity	Mangroves are habitats for marine life, birds, animals and plants.
Socio-economic well being	Mangroves can be harvested for logs, tannin, honey, herbal medicines and food.
Tourism	Mangrove ecotourism provides a source of revenue.

The peat swamp forest is a live place for important variety of flora and fauna, including recording kinds of rare and endangered species such as orang utan. Peculiar ingredients, peat swamp forests provide habitat only for the types of flora and fauna that can be adapted to these unique circumstances, including the types of fish adapted to black and aquatic ecosystems tend to have high acidity.

In terms of faunal diversity, peat swamp forests are vitally important since they are often the last intact forests remaining in the lowlands. They harbour at least 60 species of vertebrate fauna listed as globally threatened, such as the Orang-utan *Pongo pygmaeus*, Proboscis Monkey *Nasalis larvatus* and Sumatran Rhinoceros (UNDP 2006). Peat swamp forests also harbour a number of species that are confined to this habitat, such as the endangered False Gharial *Tomistoma schlegelii.*

Beside that, peat are also a source of valuable timber species, chief amongst which is Ramin *Gonystylus bancanus*. Other important timber species are *Dactylocladus stenostachys, Dryobalanops rappa*, and the Meranti group, especially *Shorea platycarpa, S. albida* and *S. uliginosa.* Coulter [14], stated that peat swamps in Malaysia contain valuable timber, evidence by Forest Department surveys. A survey was reported for Hutan Melintang Forest Reserve in South Perak, an area which contains mostly Deep Peat. The predominant species is Shorea rugosa (meranti bakau), which grows to approximately 150 feet with the first branch about 100 feet from the ground. Another notable feature was its ability for better regeneration of the Shorea rugosa. The black waters of the peat swamp forests are known to have some of the highest freshwater fish biodiversity in the world. It is likely that many new species of plants and animals will be discovered in peat swamp forests in view of the relatively small number of biodiversity surveys that have been conducted compared to other types of forest in Malaysia. According to Hogarth, mangrove areas contain some 54 species of trees in 20 genera, belonging to 16 families that constitute the "true mangroves" — species that occur exclusively in mangrove habitats and rarely elsewhere [15]

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c. Hydrology and aquatic habitat

The important benefits of peat is in protecting water quality and controlling peak flood flows mainly by reducing water velocity but also by providing a large area for storage of flood waters depending on how waterlogged the peat is already, through the water-holding capacity of peat (Figs 3 (a) and (b)). Restoration of peat wetlands is known to have a direct improvement on water quality in the rivers and estuaries. When peat soils are formed under saturated conditions, they sequester significant quantities of carbon and nitrogen and other elements. These constituents are released when the peat wetlands are artificially drained and the peat soils physically erode or oxidize rather than accumulate. Artificial drainage of peat wetlands contributes to off-site water quality impacts by speeding the pace of runoff and increasing discharge peaks. The drainage canals that were historically constructed to artificially lower the water table enhance the offsite transport of soils and their constituent. There is well-documented concern that drainage-enhanced oxidation of soils re-mobilizes nutrients. When delivered in excess to downstream freshwater streams and estuaries, these soil components become contaminants.

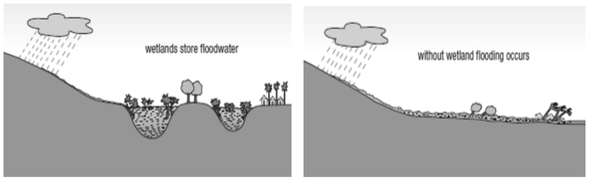

Fig. 5 (a) A large area for storage of floodwater
(b) : without flood storage

d. Agriculture

Peat soils constitute perhaps the largest readily available area of previously uncultivated land with potential agricultural use. Oil palm has been successfully cultivated on peat soils for some time with the oldest plantations now being in their second or even third replant. Other crops such as pineapple have also been grown successfully on peat. Coulter [14] stated that peat swamps in Malaysia contain valuable timber, evidenced by Forest Department surveys. A survey was reported for Hutan Melintang Forest Reserve in South Perak, an area which contains mostly Deep Peat. The predominant species is Shorea rugosa (meranti bakau), which grows to approximately 150 feet with the first branch about 100 feet (30.48m)from the ground. Another notable feature was its ability for better regeneration of the Shorea rugosa.

Peat can be considered as a gold mine for farmers. Especially in Pontian, peat lands were widely used for pineapple plantation while oil palm plantation are carried out in the other places in Malaysia. Factor that contributes to this positive effect is the organic content in peat soil, which acts as natural fertilizer thus increasing the quality of plantation and further reducing the cost for artificial fertilizer

3. Fabric and Microstructure of Peat

Critical Von Post scale of humification for each layer of peat is determined on field, right after the soils were taken out. Von Post test verifies the scale of humification of peat soil based on water and peat soil that escaped from fingers when the sample was squeezed by hand. Water and peat soil that escaped from between the fingers will be observed to identify the degree of humification scaled from H1 to H10 as given in Table 3. Observation included the turbidity of the water; either it is clear or muddy, or how the soil behaves when it was squeezed. Von Post classification test is related with the Degree of Humification (Decomposition) of organic matter. This scale shows the composition of organic matters in soil structure. The progressive degeneration of fibers is ranging from un-decayed to decayed woods and vegetations.

Table 3 Peat Classification According to Degree of Humification

Degree of humification	Description
H1	Completely undecomposed peat which releases almost clear water. Plant remains easily identifiable. No amorphous material present.
H2	Almost completely undecomposed peat which releases clear or yellowish water. Plant remains still easily identifiable. No amorphous material present.
H3 PONTIAN PEAT	Very slightly decomposed peat which releases muddy brown water but for which no peat passes between the fingers. Plant remains still identifiable and no amorphous material present.
H4	Slightly decomposed peat which, when squeezed, releases very muddy dark water. No peat is passed between the fingers but the plant remains are slightly pasty and have lost some of their identifiable features.
H5	Moderately decomposed peat which, when squeezed, releases very “muddy” water with a very small amount of amorphous granular peat escaping between the fingers. The structure of the plant remains is quite indistinct although it is still possible to recognconize certain features. The residue is very pasty.
H6 PARIT NIPAH PEAT	Moderately decomposed peat which a very indistinct plant structure. When squeezed, about one-third of the peat escapes between the fingers. The structure more distinctly than before squeezing.
H7	Highly decomposed peat. Contains a lot of amorphous material with very faintly recognizable plant structure. When sequeezed, about one – half of the peat escapes between the fingers. The water, if any is released, is very dark and almost pasty.
H8	Very highly decomposed peat with large quantity of amorphous material with very indistinct plant structure. When squeezed, about two thirds of the peat escapes between the fingers. A small quantity of pasty water may be released. The plant material remaining in the hand consists of residues such as roots and fibers that resist decomposition.
H9	Practically fully decomposed peat in which there is hardly any recognizable plant structure. When squeezed it is fairly uniform paste.
H10	Completely decomposed peat with no discernible plant structure. When squeezed, all the wet peat escapes between the fingers.

a) Parit Nipah Peat

Fig. 6.Von Post Squeezing Test

i) using hair scanner microscope   ii) using microscope

Fig. 7 Wet and Dry Parit Nipah Peat soil using hair scanner microscope and microscope

b) Pontian Peat

Fig. 8 Von Post Squeezing Test for Pontian Peat Soil

i) using hair scanner microscope   ii) using microscope

Fig. 9 Wet and Dry Pontian Peat soil using hair scanner microscope and microscope

4. Assessment of the Relevant Geotechnical Properties

a. Loss of Moisture in Peat

Zainorabiddin, A [16] studied the relationship between the equilibrium water content at 14 different drying temperatures from 15^{0}C up to 105^{0}C. Figs 10 shows the comparison of water content for peat, sand and clay tested under similar drying conditions. It is noteworthy that the peat sample showed a unique curve for moisture retention. The water retention character for clays and sand are uniform and different from that of peat. Sand samples release water totally at a lower temperature of 30^{0}C whilst in clay, the moisture is released at 40^{0}C.

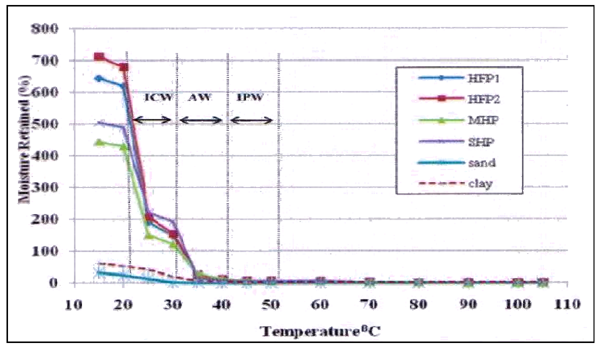

Fig. 10 Comparison of moisture content loss for different samples.

The moisture content retained for all HFP1 samples (Holme Fen peat from Cambridge) were different (in the range between 620 to 670%, see Figure 10). In the temperature range of 20^0 C to 35^{0}C there is, notably, still a variation of moisture retention in peat. At 35^0 C, it becomes consistent and constant at 40% moisture for similar rate of drying. After 60^0 C. there is no appreciable change in moisture. The figure shows very similar pattern and repeatability between the four samples. This confirms that changes in the moisture retained for peat are related to and influenced by the temperature of drying.

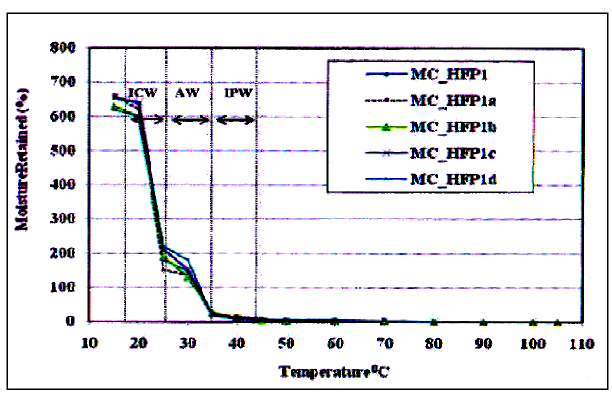

Fig. 11 Observation of moisture loss for HFP1 sample

b) Fall cone test on Peat

Liquid limit is an index property of soil which is widely used in the field of geotechnical engineering. Two methods that are popularly used in the world for the determination of liquid limit of soil are the percussion method or Casangrande (developed by Casagrande (1928,1958)) and fall cone test initially developed by the Geotechnical Commission of the Swedish State Railways [17. What the author can say that at 0-30 % of water content, the process started with the shrinkage limit. Which mean below this limit, the soil –water mixture was no longer saturated and no further volume decrease in the process of dying[18]. 30-85% of water content (between plastic and liquid limit, the plastic soil-water mixture underwent continous and permanent deformation without ruptures and exhibited certain level of shear strength that depended on the water content. [18] .Above Liquid limit phase (85-100 % of water content), soil-water mixture behaved like fluids.

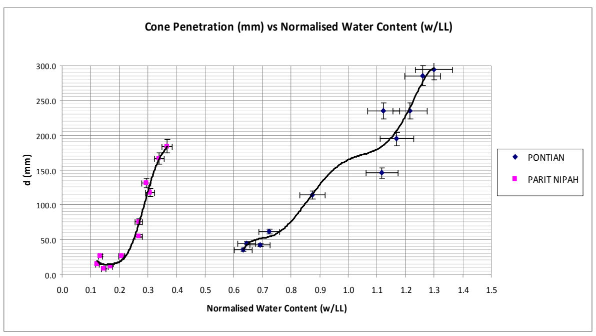

Fig. 13 Graph Depth of Cone Penetration versus Normalised water content for Parit Nipah Peat and Pontian Peat

Beside liquid limit, the fall cone test also becomes a simple method to determine undrained shear strength because of the easy of operation and give a precise reading. In this paper, the relationship between the water content and cone penetration depth is presented. At this stage, the liquid limits measured using peat soil from Parit Nipah and Pontian are compared using different shape of cone (30^0, 45^0, 60^0, and ball)

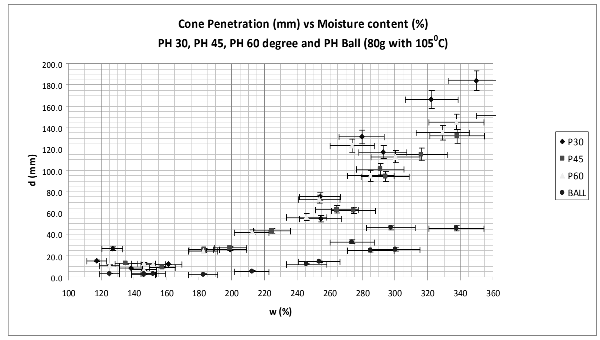

Fig. 14 Graph Water Content (%) with Penetration Depth (mm) of Parit Nipah Peat

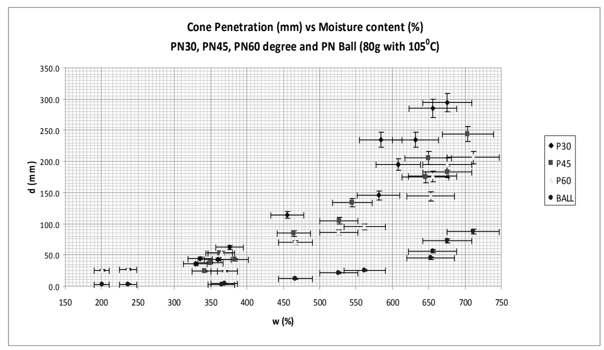

Fig. 15 Graph Water Content (%) with Penetration Depth (mm) of Pontian Peat

The test results show that the correlation between d(mm) and w(%) is clearly a non-linear relationship. All cone shapes gave similar curve and showed that the depth of penetration at 100 to 200 % of water content PH Peat and 150 to 400% of water content PN Peat give a similar value. After that the penetration increased uniformly with increasing water content. The average water content with penetration depth is shown in Figure 14 and Figure 15. It can be observed that the average water content increased with depth and the Liquid Limit of the Pontian Peat is 520% and Parit Nipah is 950% of water content.

5. Infrastructure Development Challenges with Peat Land

Stability of development on peat is a challenging problem which is mostly a consequence from settlement leading to failure. Therefore, all development projects especially building and road constructions require a specific construction method when dealing with peat. Figs 16 shows the ground surrounding one of the houses in Sibu settled a year after completion of construction. While Figs 17 shows the peat subsidence beneath a structure and by the side of it. One of the main factors that contribute to the subsidence was the fluctuation of ground water level.

Fig. 16 House settled after a year completion of the construction

Fig. 17 Peat subsidence in Parit Nipah, Johor

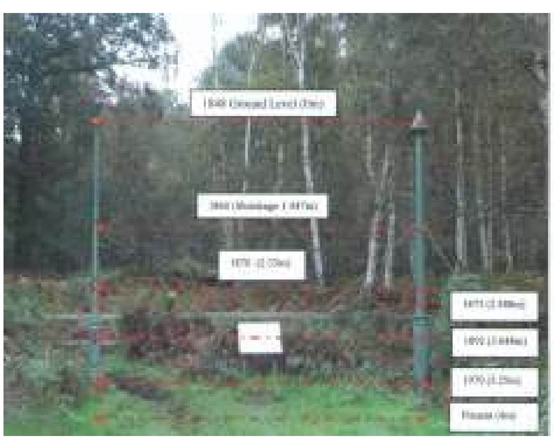

Fig. 18 Settlement of the peat at Holme Post recorded on an iron post [16]

According to Zainorabidin [16] the two cast iron posts in Figs 18 were set in place by William Wells in 1952 at the edge of Holme Lode covert. The drainage of the site has caused the ground to sink 4m during last 150 years.

Although this is a major breakthrough, much more needs to be done before any technological improvement in the construction on peat ground can be achieved. Trend for technological innovations will continue and have a strong impact on efforts to reduce the settlement rate of structures on peat foundations.

6. Sustainable Construction Method to Overcome Peat Problem

Structures construct on peat are often affected by stability due to high compressibility, low shear strength and low permeability. Therefore, the load induced by the structure may results in bearing capacity failure and large deformation. Edil [19] summarizes a number of construction options that can be applied to peat and organic soils, namely; excavation displacement or replacement; ground improvement and reinforcement to enhance soil strength and stiffness, such as by stage construction and preloading, stone columns, piles, thermal pre compression, and preload piers; or by reducing driving forces by light weight fill; and chemical admixture such as cement and lime.

a. 'Cut and Fill' or replacement:

This method is one of the oldest or conventional method by replace the poor soil with suitable imported fill materials but this method is very expensive.

b. Soil stabilization:

Soil Stabilization started to popular about 40 years ago and have seen widely used last 20 to 25 years in alternative ways to deal with soft soil. Åhnberg et al. [20] reported that originally, lime was the only binder used, but in mid 1980s cement become popular method with considerably higher strength achieved. Comprehensive trials and field works have been carried out where cement with different industrial binders has been shown to improve the mechanical properties (shear strength and compressibility) but the introduction of cement to stabilize "problematic soils" with high organic contents and high water:soil ratios has made it possible [20-22].

c. Preloading:

This method involves placing a surcharge fills on top of the soil that requires consolidation. Then once sufficient consolidation has taken place, the fill can be removed and construction takes place. Surcharge fills are typically 10-25 feet thick and generally produces settlement of 1 to 3 feet. It must remain in place for months or years, thus it will delay the construction.

d. Vertical drain:

Vertical drains are usually installed under a surcharge load to accelerate the drainage of impervious soils and thus speed up consolidation. These drains provide a shorter path for the water to flow through to get away from the soil. Time to drain clay layers can be reduced from years to a couple of months.

e. Prefabricated Vertical Drain:

This method is geosynthetics used as a substitute to sand columns. It is installed by being pushed or vibrated into the ground. Most are about 100 mm wide and 5 mm. The function of prefabricated vertical drain (PVD) is to allow drainage to take place in both vertical horizontal directions over a much shorter drainage path so that the rate of consolidation can be accelerated and the consolidation time can be reduced.

(a) (b)

Fig. 19 a) Prefabricate vertical drain at site b) close view of vertical drain.

f. Deep stabilization method :

Deep mixing method is the widely used method for stabilizing organic soils. This method originally developed in Sweden and Japan more than thirty years ago and becoming well established now. In the Japanese Geotechnical Terminology Dictionary, "deep mixing method of soil stabilization" was described as a "generic term for soil improvement involving mixing by force together with chemical stabilizers such as lime or cement within the deep ground on site". According to Yang et al;[23] Dry Mixing Method (DMM) and Dry Jet Mixing (DJM) methods are more effective for peat stabilization instead of wet mixing method.[24-25]

Fig. 20 Deep soil mixing injects cement grout columns deep into poor soil.http://www.defensemedianetwork.com

7. Conclusion

Peat swamp forests are very unique ecosystems. Wise use of peatlands is essential in order to ensure that sufficient areas of peatlands remain on this planet to carry out their vital natural resource functions while satisfying the essential requirements of present and future human generations. In the future we hope the more sustainable practices will be implemented in Malaysia.

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