GEOTECHNICAL CHALLENGES WITH MALAYSIAN PEAT

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ABSTRACT Malaysian peat is a tropical peat (Andriesse, 1988). This peat has unique characteristics, which makes it significantly different from other peat. In its natural state, this soil is normally dark reddish brown to black in colour and consists of partly decomposed leaves, branches, twigs and tree trunks with a low mineral content. These are formed through accumulation of disintegrated plant remains, which have been preserved under conditions of incomplete aeration and high water content. Hobbs (1986) stated that it was important to include and recognise the peat by not only its morphology but also by its basic engineering properties. The "special" characteristics for this soil are a high water content (>200%), high compressibility, high organic content (>75%), low shear strength (5-20kPa) and low bearing capacity (<8 kN/m^2). These geotechnical characteristics make any form of construction on this soil very challenging in Malaysia (Zainorabidin and Bakar, 2003). This paper presents an overview of previous research carried out on peat soils (Mutalib et al, 1991; Jarrett, 1997; Bujang, 2004; Zainorabidin and Bakar, 2003). Edil (2003) demonstrated the variability of the peat properties even within a single sample, leading to it being far from homogeneous, which is a prime requirement in engineering soil mechanics. The compressibility of the individual peat particles invalidates one of the prime assumptions of particle incompressibility adopted in soil mechanics This paper also discusses the challenges that geotechnical engineers have faced in Malaysia when designing and managing construction on this soil.

1.0 Introduction

Malaysia is moving forward to achieve a developed country status by 2020. The consequent rapid development within the country, coupled with a strong economic performance has resulted in vast infrastructure developments. These developments are hindered by a dearth of suitable land for development and as a consequence, areas with adverse ground conditions such as soft soil (peat, organic and marine) are being considered for infrastructure construction such as roads, housing, drainage and others.

Notable examples of such constructions that have recently been carried out are Kuala Lumpur International Airport (KLIA) and urban development in Sibu Town (Sarawak).

Jarret (1997) 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. The definition and descriptions of peat between soil scientists and engineers are diverse. Soil scientists have described peat as a soil with an organic content greater than 35%. Engineers normally define organic soils as those soils which have an organic content between 20% and 75%, whereas peats are those soils that have an organic content more than 75%. This forms a fundamental difference between the views of a soil scientist from that of a geotechnical engineer.

Peat soils have been named and classified differently across many countries. Some such names are bogs, moors, muskeg, mire, tropical swamp forests and fens. These names help characterise the peat by its differences resulting from the effect of climate and type of plant materials that constitute the peat. Accordingly, Malaysian peats are classified as a tropical peat (Andriesse, 1988). It is further sub- divided into three categories which are based on the extent and type of fiber content; viz., Sapric (<33%), Hemic (33-66%) and Fibric (>66%).

2.0 Distribution, classification and geotechnical properties of peat in Malaysia.

2.1 Distribution of peat

Malaysia has a land area of 336,745 km^2 spread over 3 main areas, namely Peninsular Malaysia (131,587 km^2), Sabah (73,711 km^2) and Sarawak (123,466 km^2). The climate of Malaysia is typical of the humid tropics and is characterised by year-round high temperature and seasonal heavy rain. Temperature ranges from 26^0 C to 32^0 C and rainfall ranges from 2000 mm to 4000 mm per annum. The very high rainfall is influenced by both north-east monsoon and the south-west monsoon.

Figure 1 shows the known occurrence of peat deposits in Malaysia. There is approximately 30,000 km^2 of peat in Malaysia accounting for about 8% of the country's land area (Mutalib et al, 1991). Sarawak has the largest peat area with 16,500 km^2 and the peats in 89% of these areas are more than 1m in depth. Bujang (2004) observed the depths for peat deposits in Malaysia were varying from 1m to 20m. The figure also shows that these deposits are predominantly along the coastal areas, except that in Sri Aman.

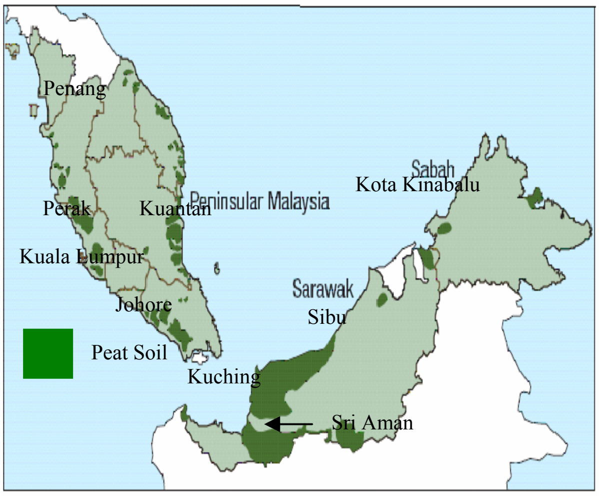

Figure 1: Location of peat swamps in Malaysia (Modified from Mutalib *et al*., 1991)

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. The ground water table in these areas is always high and occurs at or near the surface. 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.

The summary given in Table 1 shows the different characteristics of peat in Malaysia. The topography for peat soil areas in Peninsular Malaysia and Sabah is generally flat compared to that in Sarawak where it is more dome-shaped.

Distinctly the peat in the Sarawak area is mainly categorized an inland deposit.

Table 1: Characteristic of peat swamps in Malaysia (after Muttalib,1991)

Region	Location	Topography	Total Area	Characteristics
Peninsular	West Johore, Kuantan, Pekan, Selangor,Perak	Peat land is ***flat***	Approximately 80,000km^2 with 89% of it having deep peat (>1m)	Normally found in the ***coastal areas*** of the east and west coasts
Sarawak	Kuching, Samarahan, Sri Aman, Sibu, Sarikei, Bintulu, Miri and Limbang	The basin peat swamps are ***dome-shaped***	16500 km^2 with 89% of it having deep peat (>1m)	Peat occurs mainly between the ***lower stretches of the main river courses*** (basin peats) and in poorly ***drained interior valleys*** (valley peats).
Sabah	Kota Belud, Sugut,Labuk, Kinabatangan	Peat land is ***flat***	86 km^2. There were no estimates on the depths	Peat soils are found on the ***coastal areas***

The underlying geology of the peat areas in the west coast of Peninsular Malaysia and in most of the Sarawak area consists of sulfidic marine clay, while in the east coast of the peninsula, the peat is underlain by river alluvium, colluvium and sand (Muttalib et al.,1991).

2.2 Classification and geotechnical properties

Current classification systems for peat and organic soils use organic and ash content as the sole parameter in classification (Andrejko et al., 1983 and Landva et al., 1983). This however has resulted in a wide variation in the definition of peat which is compared in Figure 2. The comparison shows that peats are defined as soils with the highest organic content and organic clays as the soils with the lowest organic content. A common and useful method of determining organic content is to burn a small soil specimen in a furnace after drying at 105^{0}C for 24 hours. A comparison of measured mass before and after burning yields the ash content or loss on ignition (N). The organic content can is then being determined as:

Organic content (%) : 100-C(100-N)

where C is the correction factor for oven temperatures in excess of 450^{0}C (C=1.0 for 450^{0}C).

The threshold organic contents that separate the various soil types differ depending on the classification system adopted. However, Loughlin (2003) 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 D2487-00) defines organic soils as a separate soil class in the standard classification of soils for engineering purposes. This soil class referred to as "Highly Organic Soils (PT)" include peat and other highly organic soils.

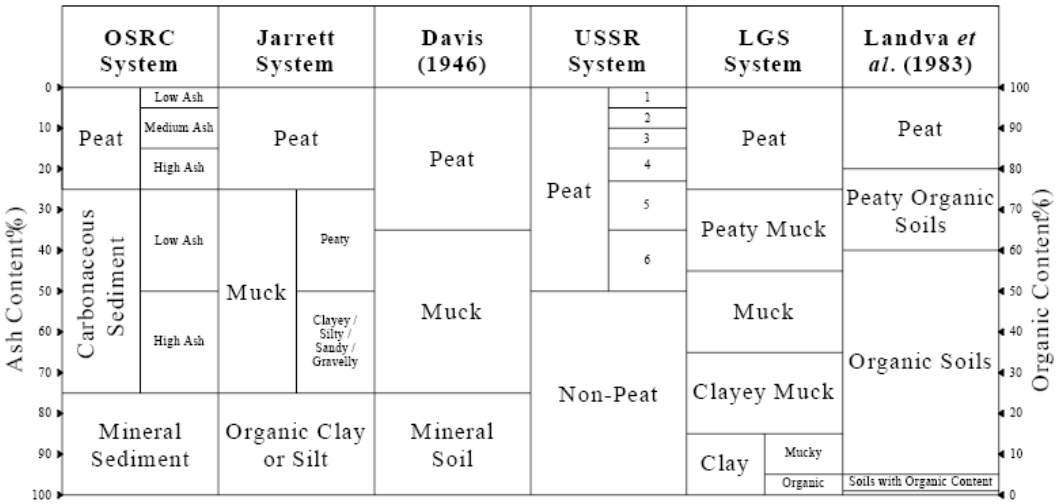

Figure 2: Comparison of classification systems used for peat and organic soils (after Andrejko *et al.* 1983)

Jarret (1995) recognised that this classification for organic soils was incomplete due to the gap between those soils that have their own different characteristics. Classification of peat soil still remains controversial (Edil, 1997). The classification of peat and organic soils adopted in Malaysia conform to that given in British Standard 5930:1981.

This classification has been improved by the Public Works Department Malaysia,
and Jarret (1995) to make this system more explicit to the Malaysian environment. It is referred to as the Extended Malaysian Soil Classification System (MSCS) and is shown in Table 2.

The MSCS system introduced the state of decomposition (or the degree of humidification) as the second important parameter to be considered after organic content. This defines the state of decomposition/decay of organic matter which gives rise to peats and organic soils. A further factor that has been considered in MSCS is the percentage of fiber content. There are three-point scales for fiber content used in the classifications for Malaysian peat (Bujang, 2004). These categories are fibrous peat (>66% fiber), hemic (33-66% fiber) and Sapric (< 33% fiber). Bujang (2004) reiterated that in conventional soil mechanics, soils are principally particulate materials but a soil sample in its entirety can simultaneously contain three phases (solid, liquid and gas phases). In the case of peat, the solid phase additionally consists of two components: organic matter and inorganic earth materials. Bujang (2004) further recommended the inclusion of important index parameters such as water content, liquid limit, specific gravity and unit weight as an addendum to the MSCS classification.

Based on the research experience with peat soils from the western Johore area, the authors agree and welcome this recommendation. The authors have evidence of the variations in the index and geotechnical properties that imply the peat soil to be very non-homogenous and anisotropic. Correlations of peat behaviour with these parameters will help engineers to understand the complex behaviour of peat soil.

Table 2 Malaysian Soil Classification Systems (MSCS) for Organic Soils and Peat (Jarret, 1995)

Soil Group	Organic Content	Group 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	

2.3 Geotechnical properties

Variations in some of the published geotechnical properties of peat are given in Table 3. A comparison of their properties has been made with that of some Malaysian marine clay. It shows that the natural water content for peats is in the range of 200~2200%. This is much higher than that in marine clay,
which has a value in the range 50-93%. The high natural moisture contents result from the water that is held in the organic matter and cells of the plant. Accordingly, the water content is higher for fibrous peat than that for other peats. Organic contents in the range of 65~98 % are reported.
Liquid limit and plastic limit properties also show higher ranges of 190~550% and 100~297%, respectively. However, the author has experienced that it was not possible to determine the plastic limit peat. The presence of the fibres makes the determination of Atterberg limits difficult. According to Hobbs (1986), it was impossible to carry out plastic limits tests on pure bog peats. On the other hand, even if the peats are 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.
According to Hobbs (1986) differences in the liquid limit depends on the type of plant detritus, the degree of humidification and the clay content. Accordingly the liquid limit for the Malaysian peat is mush less than that reported by Hobbs (1986) of 200-600% for fen peat and 800-1500% for bog peat. Specific gravity of peat is influenced by that of the cellulose (1.58) and of lignin (1.40). Authors such as Edil(1997), Hobbs(1986) and Haan(1997) report values in the range of 1.1 to 1.9. There is also a

dilemma as to whether the peat behaves as a granular material or as a cohesive material in shear. Any frictional characteristics result from the macrostructure of the network of fibres.

The unique settlement characteristics in peat results from creep at a constant vertical effective stress (secondary compression which can account for as much as 60% of the total settlement).

Table 3 Geotechnical properties of some of Malaysian soils

Soil Deposit	Carey Island Marine Clay	West Malaysia Peat and Organic Soil	East Malaysia Peat and Organic Soil	Johore Hemic Peat
Natural water content, W (%)	28-93	200-700	200-2207	230-500
Liquid limit, LL (%)	33-104	190-360	210-550	220-250
Plastic Limit, PL (%)	24-41	100-200	125-297	-
Plasticity Index, PI (%)	21-63	90-160	85-297	-
Specific gravity (G_s)	2.55-2.68	1.38-1.70	1.07-1.63	1.48-1.8
Organic content (%)	-	65-97	50-95	80-96
Unit weight (kN/m^3)	13-16.9	8.3-11.5	8.0-12.0	7.5-10.2
Undrained Shear strength (kPa)	-	8-17	8-10	7-11
Compression Index, C_c	0.5-1.25	1.0-2.6	0.5-2.5	0.9-1.5
Refs.	Shanul et al (2004)	Bujang (2004)	Bujang (2004)	Zainorabidin and Ismail (2003)

The ratio of the coefficient of secondary compression to compression index (C_o/C_c) is 0.06 for peat whereas for a granular material it can be the lowest value of 0.02 (Mesri et al. 1997)

3.0 Some issues and challenges from a geotechnical perspective

In the following sections, the authors give briefly discussions on some of the issues that geotechnical engineers in Malaysia face when designing and managing construction on these peat soils.

3.1 Representative soil sampling

Andriesse (1988) described the composition of tropical woody peat to be very complex and that it consists of a compacted mass of semi-decomposed plant remains of tree stumps, roots, twigs and leaves. Zainorabidin and Bakar (2003) reported that sampling of hemic and fibrous peats using conventional undisturbed samplers was difficult. The difficulties arose not only from the high percentage of water content (> 200%) but also from the fibrous/spongy layers (>50% fiber) that make the sample difficult to cut without causing compression, particularly if using a tube sampler.
In the paper by Yonebayashi (2003) it was reported that trenches 10m long and 1m deep were dug for the investigation of the soil profile at the Integrated Peat Soil

Research Station (IPRS) in Pontian, Johor. Figure 3 gives a log of their observations.

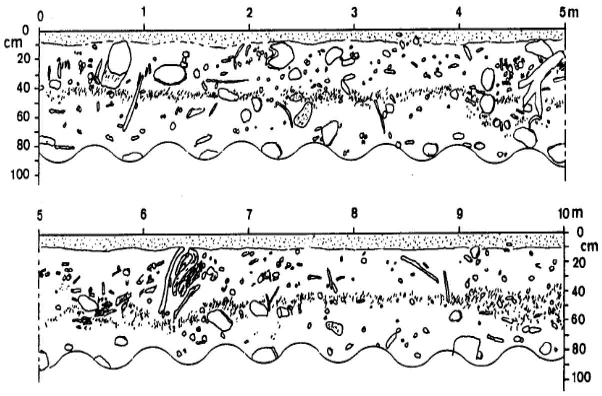

Figure 3: Woody peat profile in the Pontian MARDI Experimental Station (After Yonebayashi, 2003)

Edil (2003) suggested the conventional thin-wall sampling tubes used for taking "undisturbed" samples of soft clays may not be suitable and adequate for peats. Tensile resistance of fibres, internal redistribution of water and the peat compression, plays a role in disturbing the soil when forcing a soil sampler into the ground. The University of New Brunswick developed a 100-mm diameter piston sampler to minimise these effect and has been used in sampling fibrous peats and soft organic bay sediments (Landva et al. 1983). The disturbance can also be minimized by obtaining block samples (e.g. see Hobbs, 1986 and Edil, 2003). Edil (2003), suggested that large block samplers such as Sherbrooke sampler (250mm in diameter) and Laval sampler (200mm in diameter) used for sampling clays can be used for organic soils and peats.

3.2 Laboratory testing and site investigation

There are questions raised regarding the representative interpretation of the mechanical parameters from the conventional in-situ tests (Edil, 1997; Haan, 1997 and Jarret, 1997). Landva et al. (1983) recommended test fills as opposed to relying on laboratory or field tests in designing embankments on such deposits.

3.3 Construction methods

Different construction methods are used when peat and organic soil conditions are met (Edil 2003). Mc Manus et al. (1997) suggested three optional method construction techniques that can be adopted which was based on the depth.

Table 4 Constructions method based on the depth of peat deposit

Depth	Methods
< 3m	Removal and Replacement
3m – 10m	Preloading, Stage Construction with vertical and sand drain, lightweight fills and surface mattresses, stone column and etc.
>10m	Deep stabilization techniques (pile, dynamic compaction, etc.)

These were used in the Semariang Ring Road (1.4 km) and North Kuching Ring Road. In the case of the Semariang Ring Road project where the site was overlain by 7m deep soft peat and organic soils with very high moisture content (1000-1700%), low specific gravity (1.38 – 1.54) and low bulk density (1.015-1.025 Mg/m^3), the method adopted was to excavate the soft deposits to a depth of 4.5m to 5.5m and replaced them with granular fill material. Extensive dewatering was used due to the high water content. In another project, the parameters of subsoil had even higher natural moisture contents (280-1000%), and compressibility (Cc range 5.6 to 11.0). In this case a bamboo mattress combined with non-woven geotextile was used as a separation layer on which a platform could be developed.

4.0 Case histories

The geotechnical challenges at a housing development project, in Bintulu, Sarawak is described in Wong (2003). Serious diagonal cracks appeared near doors, windows and openings of the houses even before the construction was complete. The observed settlement for the first year exceeded 300 mm and the differential settlements were found to be more than 1:150 for most buildings. The geotechnical contractor for this project proposed the installation of vertical drains to an average depth of 21 m at 2 m spacing.

Table 6 Some Malaysian case histories related to construction projects on peat soil area.

Report	Location	Project	Soil Types	Problems
Wong (2003)	Sri Aman (Sarawak)	Earth filling project for 6 acre site for building site and football field.	Underlain with 5.6m to 7.0m thick very soft dark brown peat and woods.	Settlements continued after reaching the platform level for earth filling.
	Bintulu (Sarawak)	Earth filling 4.5 acre site for housing development	8m to 13m thick very soft dark brown peaty clay with decomposed wood.	The settlement for first year exceeds 300mm and the differential settlements were found to be more than 1:150 in many block houses.
Tai et al (2004)	Sibu Town (Sarawak)	Part of Sibu Town	Substantial peat formations more than 10 m depth	Ground subsidence caused by uncontrolled land filling and lowering ground water

A 3 m surcharge was further placed for a period of 3 months. The predicted settlement with the surcharge was 1090 mm. Their predictions were proved wrong as the measured settlements 3 months after the surcharge placement was 1440 mm and the settlement after 6 months was 2800mm. The total average fill thickness finally required was about 7.3m more than earlier predicted. Despite this initial.
preconsolidation the settlements resulting from the housing construction were significant to produce diagonal cracking. Further challenging case studies related to Malaysian peat soils are outlined in table 6.

5.0 Conclusions

The paper has given an overview of the properties of Malaysian peat. It has emphasized that;

- Peat, by virtue of its heterogeneity, is a problematic soil.
- The high natural water contents coupled with the extraordinary compressibility of the organic material cause undesirable and unpredictable settlement.
- The performance of peat is dominated by the macro and micro structure which is continuously changing with the material digenesis.

- Research leading to a better understanding of the performance of peat is urgently required for improved better geotechnical design.

6.0 References

Andrejko, M.J., Fience, F. & Cohen, A.D. 1983. Comparison of ashing techniques for determination of the inorganic content of peats, *Testing of peats and organic soils,* ASTM Special Technical Publication nr. 820, pp 5-20.

Andriesse, J.P. 1988. Permanent constraint in peat reclamation. In nature and management of tropical peat soils. *FAQ Soil Buletin* **59:**81-91

Bujang B.K, 2004. Organic and peat soils engineering. Universiti Putra Malaysia Press, ISBN 983-2871-08-5.

Haan, E.J. 1997 An overview of the mechanical behaviour of peats and organic soils and some appropriate construction techniques. In *Proceedings of Recent Advances in Soft Soil Engineering,* ed. Huat and Bahia, pp.85-108.Sarawak.

Edil T. B.,1997. Construction over peats and organic soils. In *Proceedings of Recent Advances in Soft Soil Engineering,* ed. Huat and Bahia, pp.85-108.Sarawak.

Edil T. B. 2003. Recent advances in geotechnical characterization and construction over peats and organic soils, In *Proceedings of 2nd International Conference on Advances in Soft Soil Engineering and Technology,* ed. Huat et al, pp.3-25 Putra Jaya, Malaysia.

Jarret, P.M.,1995. Geoguide 6. Site Investigation for Organic Soils and Peat. JKR Document 20709-0341-95. Institut Kerja Raya Malaysia.

Jarret P.M 1997. Recent development in design and construction on peat and organic soils. In *Proceedings of Recent Advances in Soft Soil Engineering,*ed. Huat and Bahia, pp.1-30.Sarawak.

Landva, A.O., Korpijaako, E.O & Pheeney, P.E. 1983. Geotechnical classification of peats and organic soils, *Testing of peat and organic soils,* ASTM Special Technical Publication nr. 820, pp. 37-51

Loughlin, C.D. and Lehane, B.M. 2003. A Study of the link between composition and compressibility of peat and organics soil. In *Proceedings of 2nd International Conference on Advances in Soft Soil Engineering and Technology,* ed. Huat et al, pp.135-152 Putra Jaya, Malaysia.

Mc Manus, K., R. Hassan & F.Sukkar, 1997. Founding Embankments on Peat and Organic Soils. In the *Proceedings Conference on Recent Advances in Soft Soil Engineering,* ed. Huat and Bahia, pp. 351-367.Sarawak.

Mesri, G.S., Ajlouni, M.A. and Chen, C.S. 1997. Secondary compression of peat with and without surcharging. *J. Geotech. Geoenv. Engr* 123 (5), 411-421

Mutalib, A.A., Lim, J.S, Wang, M.H, and Koonvai, L., 1991. Characterization, distribution and utilization of peat in Malaysia.. In *Proceeding of International Symposium on Tropical Peatland* 6 – 10 May 1991, pp. 7-8. Sarawak.

N.B Hobbs. 1986. Mire morphology and the properties and behaviour of some British and foreign peats, *Quart. J. of Eng. Geol.,* Vol. 19, pp. 7-80

Shahnul H. M., Taha. M.R., Mustafa. A. 2004 Some engineering properties of Carey Island Clay, Selangor. In *Proceedings of The Malaysian Geotechnical Conference 2004* ed. Chan. P. Kuala Lumpur.

Tai L.Y, Lee K.W and Ting W.H.2004. Some aspect of peat formation in Sibu Town and related engineering problem. In *Proceedings of The Malaysian Geotechnical Conference 2004* ed. Chan.

P. Kuala Lumpur Wong, K.M., 2003. Earth-Filling– Experiences on peat soils at Sri Aman, Sibu & Bintulu, In *Proceedings of 2nd International Conference on Advances in Soft Soil Engineering and Technology,* ed. Huat et al., pp. 669-679. Putra Jaya, Malaysia.

Yonebayashi, K., 2003. Morphological characteristics and chemical properties of tropical woody peat in Southeast Asia. In *Proceedings of 2nd International Conference on Advances in Soft Soil Engineering and Technology,* ed. Huat et al, pp. 27-38 Putra Jaya, Malaysia.

Zainorabidin, A. and Bakar, I. 2003. Engineering properties of in-situ and modified hemic peat soil in Western Johor. In *Proceedings of 2nd International Conference on Advances in Soft Soil Engineering and Technology,*ed.Huat et al, p.173-182 Putra Jaya, Malaysia