GEOTECHNICAL CHARACTERISTICS OF PEAT

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Abstract: Peat soil is encountered in many areas and generally originates from plant/animal remains and is considered partly as decomposed biomass (Adnan and Wijeyesekera, 2007). Due to this composition, the structure of this soil is very different when compared with inorganic soils like clay, sand and gravel. Peat has a high compressibility, low shear strength, high moisture content and low bearing capacity (Bujang, 2004, Adnan et al., 2007). The behaviour and composition of peats in different geographical areas are different from one another, accentuating the need in soil engineering for a useful geological classification of peat soils. This paper focuses on presenting a comparative overview of the characteristic geotechnical properties for these soils. It also examines and discusses the effects of composition on the basic properties and behaviour of each soil, supported by case studies from Malaysia.

1. Introduction.

Peat soils occur in many countries and they are often described differently from both a qualitative and quantitative perspective. Peat is formed naturally through the decomposition of plant and animal matter under anaerobic conditions that take place over long periods. It is also given several different names, in order to characterise its differences resulting from the effect of climate and type of plant materials that constitute the peat. Although the same definition of peat may be similar, the characterization of this soil normally is defined by its inherent locality.

In terms of geotechnical engineering, peat is commonly recognised as a material with high compressibility and low bearing capacity and therefore being unsuitable as foundation materials for any construction works (Adnan et al., 2007). However, the rapid development in many countries, coupled with a strong economic performance has resulted in vast infastructure development. These developments are hindered by a dearth of suitable land for development and this provides the motivation for further research into the properties of soil in areas with adverse ground conditions, such as peat, with a view to finding means for infrastructure construction such as roads, housing, drainage and others.

2. Classification of Peat.

Literature review showed that peat soils have accumulated during the last 20,000 years (Hobbs, 1986). As peat is a type of soil that contains a high proportions of dead organic matter, the factors that cause peat to accumulate may be similar the world, over but different types of peatlands develop because of differences in climate, soil type and plant species. Peat is included in soil classification systems under names such as ‘peat soil’, ‘muck soils’, ‘bog soil’, and ‘organic soils’, ‘moors’, ‘muskegs’, ‘mires’, ‘tropical swamp forests’ and ‘fens’. One of the issues still facing peat engineering is the lack of satisfactory and internationally accepted definitions and classifications.

Table 1: Comparison of classification systems used for peat and organic soils (Leong and Chin, 2000)

<table>
<tr><th colspan="2">System</th><th colspan="2">OSRC (Andrejko et al. 1983)</th><th colspan="2">Jarrett (Andrejko et al. 1983)</th><th>Davis (1946)</th><th colspan="2">USSR (Mankinen & Gelfer 1982)</th><th>LGS (Kearns & Davidson 1983)</th><th>ASTM D4427-92 (1997)</th></tr>
<tr><td rowspan="20">Ash Content (%)</td><td>5</td><td rowspan="5">PEAT</td><td>Low Ash</td><td colspan="2" rowspan="5">PEAT</td><td rowspan="7">PEAT</td><td rowspan="10">PEAT</td><td>1</td><td rowspan="5">PEAT (Inorganic Texture)</td><td rowspan="5">PEAT</td></tr>
<tr><td>10</td><td rowspan="2">Medium Ash</td><td>2</td></tr>
<tr><td>15</td><td>3</td></tr>
<tr><td>20</td><td rowspan="2">High Ash</td><td rowspan="2">4</td></tr>
<tr><td>25</td></tr>
<tr><td>30</td><td rowspan="10">CALCAREOUS SEDIMENT</td><td rowspan="5">Low Ash</td><td rowspan="10">MUCK</td><td rowspan="5">PEATY</td><td rowspan="2">5</td><td rowspan="4">PEATY MUCK (Inorganic Texture)</td><td rowspan="15">ORGANIC SOILS</td></tr>
<tr><td>35</td></tr>
<tr><td>40</td><td rowspan="8">MUCK</td><td rowspan="3">6</td></tr>
<tr><td>45</td></tr>
<tr><td>50</td><td rowspan="4">MUCK (Inorganic Texture)</td></tr>
<tr><td>55</td><td rowspan="5">High Ash</td><td rowspan="5">Clayey/ Silty/ Sandy/ Gravelly</td><td colspan="2" rowspan="10">NON-PEAT</td></tr>
<tr><td>60</td></tr>
<tr><td>65</td></tr>
<tr><td>70</td><td rowspan="4">Inorganic Texture MUCK</td></tr>
<tr><td>75</td></tr>
<tr><td>80</td><td colspan="2" rowspan="5">MINERAL SEDIMENT</td><td colspan="2" rowspan="5">ORGANIC CLAY OR SILT</td><td rowspan="5">MINERAL SOIL</td></tr>
<tr><td>85</td></tr>
<tr><td>90</td><td rowspan="2">MUCKY Inorganic Texture</td></tr>
<tr><td>95</td></tr>
<tr><td>100</td><td>Inorganic Texture</td></tr>
</table>

Current classification systems for peat and organic soils use organic and ash content as the sole parameters for classification. This, however, has resulted in a wide variation in the definition of peat, which is compared in Table 1. The threshold organic contents in peat that separate the various types usually differ, depending on the classification system adopted.

Peat in northern temperate regions of the world is formed normally from the remains of grasses, sedges and bog mosses. Hobbs (1986), gave excellent summaries of the development and properties of British peat. There are two types of peat; known as fen and bog peat. The morphological differences between fen and bog peats are attributed to the types of plant remains that occur in the peat and their mode of origin. He explained that the differences lie in the degree of humification, structure, fabric and proportion of mineral material contained in the peat, and this in turn affects their behaviour from an engineering viewpoint.

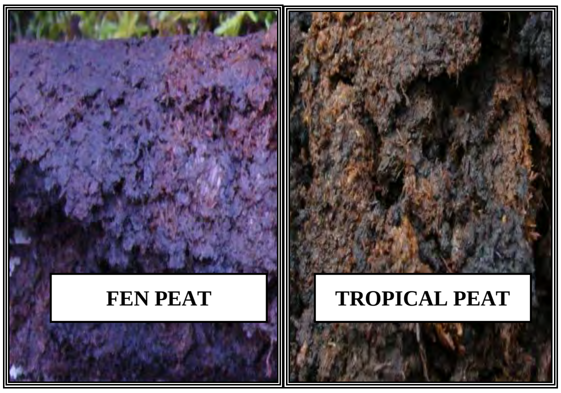

Figure 1: Two different types of peats

Bog receives water solely from rain and/or snow falling on its surface meanwhile fen receives water and nutrients from the soil, rock and groundwater as well as rain and/or snow. However, in tropical peats like Malaysia, it consists mainly of sediments from woody remains such as roots, branches and tree trunks (Adnan et al., 2007). The colour of peat soils in Malaysia is generally dark reddish brown to black. Figure 1 shows two types of peat soils.

Table 2: Comparison of geotechnical properties from different locations

Sample Designation	Description	Water Content (%)	Organic Content (%)	Liquid Limit (%)	Specific Gravity	Unit Weight (kN/m^3)	Refs.
West Malaysia	Amorphous Peat	200-700	65-97	190-360	1.38-1.70	8.3-11.5	Al-Raziqi et al., 2003
East Malaysia	Fibrous Peat	200-2200	50-95	210-550	1.07-1.63	8.0-12.0	Bujang, 2004
Johore, Malaysia	Hemic Peat	230-500	80-96	220-250	1.48-1.8	7.5-10.2	Zainorabidin and Ismail, 2003
Holme Fen, British	Fen Peat	500-600	>98	800-1500	1.40-1.60	9.5-10.5	Hutchinson, 1980
Cumbria, British	Bog Peat	200-1000	>98	200-600	1.80	8.5-11.0	Hobbs, 1986
Sri Lanka	Amorphous Peat	200-800	20-50	200	1.5-2.2	7.5-10.0	Karunawardena et al., 2007

3. Physical Properties of Peat.

The physical study of peat has been done by many researchers, especially engineers, to ensure that any constructions on peat based grounds are safe after completion (Edil, 2003). The main aspects of these studies were focussed on physical characteristics such as moisture content, liquid limit, organic content, specific gravity. In this section, a review on some of these geotechnical characteristics and properties are discussed and indicated in Table 2.

Review of literature indicates that peat soil is very variable in its properties, both from one deposit to another and from point to point in the same deposit. The moisture content for east Malaysian peat ranged between 200% to 2200%. However, Zainorabidin and Ismail (2003), conducted several tests on Johore Hemic peat and found that the natural water content for these ranged from 230% to 500%. Other researchers investigating West Malaysian peat soil include Al-Raziqi et al. (2003), who found some properties of Malaysian peat soils with values similar to those indicated in Table 1. All these figures indicate that the Malaysian peat soil varies with different geographical locations even though the natural water content may be similar. This is due to the influence of different agricultural history of the area and rainfall intensity.

Furthermore, the sampling location might differ as some were taken from coastal areas and others from midlands. As in the case with British peat soil, there are two types of peat, namely bog and fen. The natural water contents for bog seems to be similar to samples taken from East Malaysian peat soil whereas for fen its characteristics, if not the same, are similar to some West Malaysia and Johore peat soil.

In the drying process to determine the water content of peat, the technique employed should be carefully selected to avoid unnecessary charring of the organic component in peat, which would produce in consistent water content values. Some researchers used a lower temperature between 50^0C to 95^0C whereas the standard drying technique of soil needs to be done at 105^0C for twenty-four hours. Skempton & Petley (1970) and Kabai & Farkas (1988), conducted some tests and found that the loss of organic matter at 105^0C was insignificant while drying at a lower temperature retained a small amount of moisture.

Zainorabidin & Ismail (2003), further investigated the effect of the drying temperature on hemic peat soil and produced Figure 2 showing that how the drying duration decreases as the temperature increases.

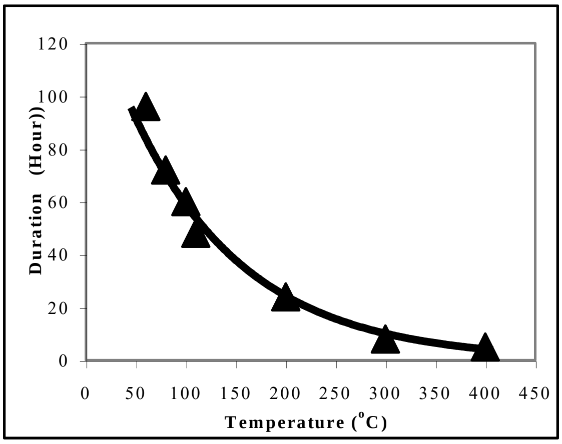

Figure 2: Duration versus drying temperature (^{0}C) Zainorabidin and Ismail, (2003)

For a drying temperature of 60^0C, the drying duration needed is 96 hours while for a drying temperature of 400^0 C, the duration is only 5 hours. However, from laboratory studies it can be deduced that a suitable temperature for hemic peat soil is restricted to between 100^0C to 200^0C, requiring durations of 24 hours to 60 hours.

The ability for peat soil to retain moisture in its unique structure is quite different from any others soil such as clay. This is perhaps due to the presence of organic matter and botanical remains. The existence of these elements might further contribute towards *free-water* movement in the soil, which might yield increases in the moisture content indicated by tests.

Hobbs (1980), determined the differences in the liquid limit of peat and explained that this depended on the type of plant detritus, the degree of humidification and the clay content. As for the liquid limit of Malaysian peat, these gave values that ranged from 190 to 550%. Accordingly, the liquid limit for the Malaysian peat is much less than that reported by Hobbs (1986) of 200-600% for fen peat and 800-1500% for bog peat. The specific gravity values of peat are influenced by that of cellulose (1.58) and of lignin (1.40). Edil (2003) and Hobbs (1986) reported that the specific gravity varies in the range of 1.1 to 1.9.

As for organic content in peat, Malaysian peat contains 50% to 97% whereas British peat contains more than 98%. The reason for the difference might be the types of plants cultivated or grown in the peat areas in Malaysia and Britain. The Malaysian peat might have originated from a less dense agricultural land area than the British peat. Thus, the percentages of organics can be different.

The unit weights of peat soils in Malaysia and Britain seem to have similar values ranging from 8.0 to 12.0kN/m^3.The unit weight of a soil is defined as the weight of a unit volume. The performance of peat can be hypothetically assumed to be dominated by its macro and microstructure that continuously changes with the diagenesis of the material.

4. Shear Strength Characteristic.

Shear strength is a fundamental property required in geotechnical design and analysis. Various researchers have studied this property and the reported results indicate important differences in behaviour from inorganic soils both qualitatively and quantitatively. Haan (1997), reported that both undrained shear strength and effective strength parameters of many peats increase with increasing water content or decreasing unit weight. This result seemingly supports the intuitive behaviour that can be attributed to the fiber effects and the fact that the fiber content, in general, increases with increasing water content and decreasing unit weight.

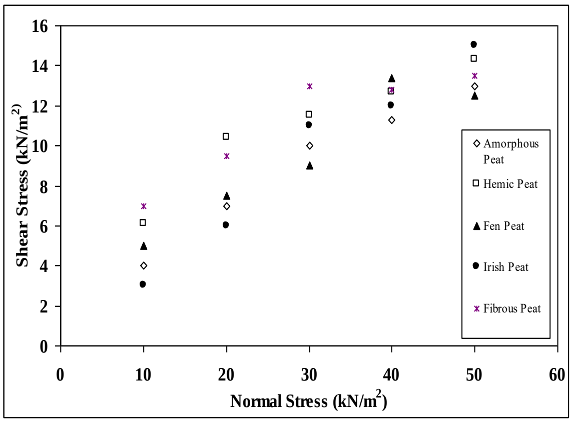

Figure 3: Normal stress versus shear stress

Figure 3 shows the results for the shear strength with different types of peat using simple shear tests. The results showed that the cohesion value, c is very low in the range, 2kPa to 8kPa, while the friction angle is less than 30^0. However, fibrous peat showed values of c and the angle of friction higher compared than other types. Lechovisz (1993) stated that the results from the simple shear tests give lower strength than triaxial compression tests because of the fiber orientation (typically horizontal) relative to the shear plane. He also determined that the reduction due to this effect could be as much as 25%.

Edil (2003), stated that the presence of the fibers can influence the strength of peat in that the shear resistance continues to develop at high strain values without a significant peak behaviour and will exhibit reduced K_o values compared to that of clays. K_0 represents the one dimensional lateral earth pressure coefficient under confined conditions at rest condition.

5. Consolidation Characteristics.

One dimensional consolidation tests were conducted to assess the compressibility characteristics. The loading was applied in increments with values of 10, 20, 40 to 80 kN/m^2 followed by unloading. These stress levels were selected considering the fact that these soils are normally encountered near the surface levels and have a maximum thickness in the range of 10-12m. The capacity of this material to retain high water contents at elevated stress levels is low. They are generally weak in their natural states but can be subjected to significant strain gain with consolidation.

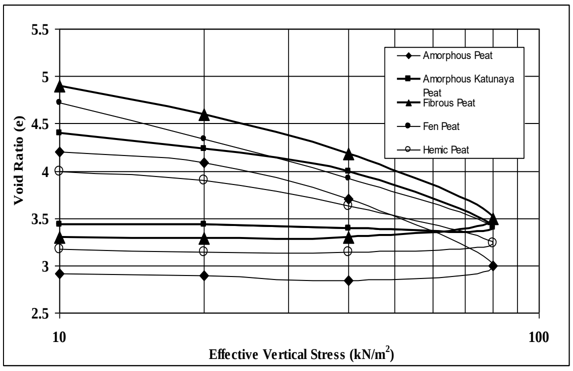

Figure 4: Effective vertical stress versus void ratio

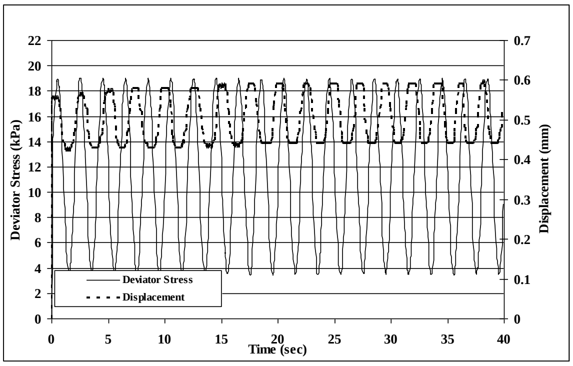

Figure 5: Axial deformation response to cyclic deviator stress application on peat sample (0.5Hz,σ_3=200kPa)

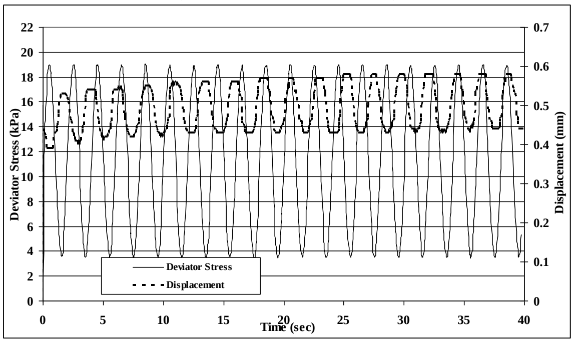

Figure 6: Axial deformation response to cyclic deviator stress application on peat sample Time (1 Hz, σ_3=200kPa)

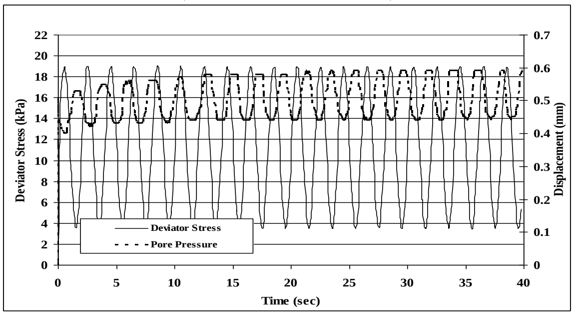

Figure 7: Axial deformation response to cyclic deviator stress application on peat sample (1.5Hz, σ_3=200kPa)

Figure 4 shows the relationship between the void ratio, e and the effective vertical stress. Compared with the conventional methods used with mineral soils, the analysis of compression presents certain difficulties because the curves obtained and behaviour exhibited by them shows only a little similarity to the clay. The difference becomes particularly apparent at low stress levels. The primary consolidation for this material is very rapid with large secondary compression. Accordingly, the complete compression or settlement process may take a longer time.

6. Cyclic Triaxial Tests on Peat.

100mm diameter, 200mm long samples of Fen peat were initially consolidated to an effective stress of 50 kPa at a cell pressure of 200 kPa. The sample was subjected to cyclic loading with stress deviation amplitude of 15 kPa. The displacements of Figures 6, 7 and 8 are all in phase with the applied oscillating stress at three different frequencies This is attributed to the inertial properties of the soil being insignificant at these relatively low frequencies.

Figures 8, 9 and 10 illustrate the accompanying pore water pressure responses observed during the same tests. It is seen that at 0.5 Hz the amplitude of the pore water pressure response was constant. Beyond a frequency of 1Hz the pore pressure showed signs of increase with time. These indicate that with higher frequency of loading liquefaction conditions can be anticipated.

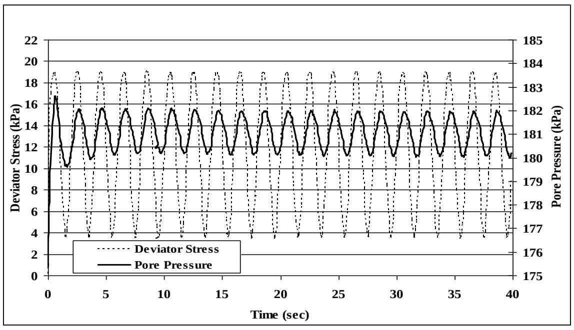

Figure 8: Pore water pressure response (0.5Hz, σ_3=200kPa)

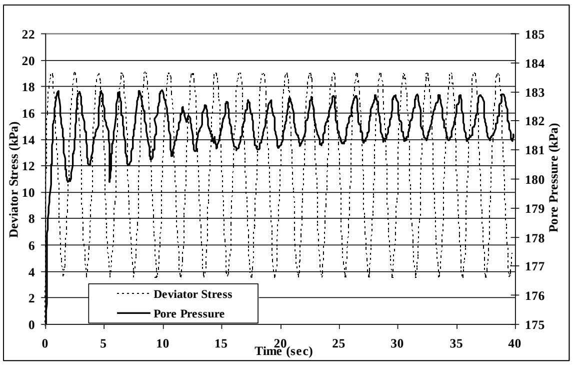

Figure 9: Pore water pressure response (1Hz, σ_3=200kPa)

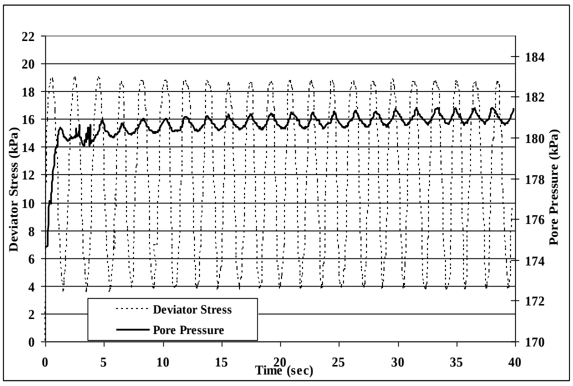

Figure 10: Pore water pressure response (1.5Hz, σ_3=200kPa)

7. Conclusion

As discussed previously, there remain challenges regarding understanding of peat soils and utilizing it for engineering purposes. In this paper, some pertinent matters have been discussed and emphasized and these are summarised as follows:

- Different geographical locations in different climates will generate different and unique properties of peat.
- Botanically different peat properties will give different engineering characteristics and behaviour.
- Research leading to a better understanding of the performance of peat is urgently required for better geotechnical design.
- Tests show that peats can reach liquefaction conditions at escalated frequencies of loading.

References

Adnan, Z. and Wijeyesekera, D.C. (2007) Geotechnical Challenges With Malaysian Peat. In *Proceedings of The Advances Computing and Technology 2007 Conference, 23 January 2007,* ed. Stephen et al., 252-261. London, United Kingdom.

Adnan, Z, Wijeyesekera, D.C and Masirin, M.I.M. (2007) Comparative Study of Malaysian Peat and British Peat Pertaining to Geotechnical Properties. In *Proceedings of Sri Lankan geotechnical Society's First International Conference on Soil and rock Engineering, 5-11 August 2007,* ed. Pinnaduwa H.S.W, Colombo, Sri Lanka.

Al-Raziqi, A.A., Bujang, B.K.H. and Munzir, H.A. (2003) Index Properties of Some Tropical Peat and Organic Soils. In *Proceedings of 2nd International Conference on Advances in Soft Soil Engineering and Technology,2-4July 2003,* ed. Huat et al, 183-190.Putra Jaya, Malaysia.

Bujang, B.K. (2004) *Organic and peat soils engineering*. Universiti Putra Malaysia Press.

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 2-4 July 2003,* ed. Huat et al, 3-25, Putra Jaya, Malaysia.

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, 85-108, Sarawak, Malaysia.

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

Kabai, J. and Farkas, K. (1988) Strength and deformation tests of Hungarian peats. *In the Proceedings of 2nd Baltic CMSFE* Conference, Tallin: 48-54.

Karunawardena, W.A, Oka, F., Kimoto, S. and Kulatilak, S.A.S.(2007) Prediction of consolidation behaviour of Sri Lankan peaty clay using an elasto-viscoplastic Theory. In *Proceedings of Sri Lankan geotechnical Society's First International Conference on Soil and rock Engineering, 5-11 August 2007,* ed. Pinnaduwa H.S.W, Colombo, Sri Lanka

Lechovisz, Z. (1993) An evaluation of the increase in shear strength of organic soils. In *Proceedings of The International Workshop on Advances in Understanding and Modelling the Mechanical Behaviour of Peat.* ed. Haan, Termaat & Edil, Balkema, Rotterdam.

Leong, E.C. and Chin, C.Y. (2000) Geotechnical characteristics of peaty soils in Southeast Asia. In *Proceedings of GeoEngineering 2000*, Melbourne, Australia

Skempton, A.W. and Petley, D.J. (1970) Ignition loss and other properties of peats and clays from Avonmouth, King's Lynn and Cranberrry Moss. Geotechnique, **20 (4)**: 343-356.

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