

Deformation and Shear Strength Characteristics of Some Tropical Peat and Organic Soils

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ABSTRAK

Tanah-tanah gambut dan organik lazimnya terdapat sebagai endapan yang tersangat lembut, yang merupakan sebahagian daripada sistem tanah berair. Tanah-tanah ini boleh juga terdapat sebagai stratum di bawah endapan tanah yang lain. Tanah-tanah ini lazimnya dikategorikan sebagai tanah bermasalah oleh kerana ia tersangat boleh mampat serta mempunyai kekuatan ricih yang sangat rendah. Di beberapa negara seperti Malaysia, tanah sebegini terdapat dengan banyaknya. Oleh yang demikian penggunaan kawasan-kawasan sebegini semakin diperlukan dengan berkurangnya kawasan-kawasan lain yang lebih sesuai. Dengan itu parameter kejuruteraan serta kaedah pembinaan yang bersesuaian perlu dicari. Kita perlu mengembangkan pengetahuan kita mengenai tanah-tanah sebegini, khususnya dari aspek kejuruteraan seperti kebolehmampatan dan kekuatan ricih tanah. Kertas kerja ini memerihalkan kajian yang telah dijalankan di makmal dan juga di lapangan mengenai ubah bentuk dan kekuatan ricih tanah organik dan gambut tropika. Sampel-sampel tanah diambil di beberapa lokasi di Malaysia, Johor, Perak, Sarawak dan Selangor. Tanah-tanah ini mempunyai kandungan organik yang ber julat di antara 50% hingga 95%. Indeks mampatan tanah didapati bertambah dengan bertambahnya kandungan organik dan air tanah. Manakala kekuatan ricih tanah berkurangan dengan bertambahnya kandungan organik dan air tanah. Kekuatan ricih tanah turut didapati dipengaruhi oleh darjah pereputan tanah. Tanah dengan serat yang tinggi mempunyai kekuatan ricih yang tinggi.

ABSTRACT

Peat and organic soils commonly occur as extremely soft, unconsolidated surficial deposits that are an integral part of the wetland systems. They may also occur as strata beneath other surficial deposits. These soils are problematic as they are very highly compressible and are of very low shear strength. In countries like Malaysia, peat and organic soils are found in abundance. Utilization of this marginal ground is required in increasing number of instances in the recent years. Hence suitable geotechnical design parameters and construction techniques needed to be found for this type of ground condition. This paper presents results of laboratory and field tests on the deformation and shear strength characteristics of tropical organic and peat soil. The soil samples were collected from several locations in Malaysia, namely from the states of Johore, Perak, Sarawak and Selangor. These soils represented tropical peat and organic soils with organic content ranging from 50% to 95%.

The soil compression index is found to increase with increase in the organic content and natural moisture content. While for case of undrained strength, the shear strength of tropical peat and organic soil is found to decrease with increase in the organic content and natural moisture content. The shear strength of the soil is also dependent on the degree of humification of the soil, with more fibrous soils having higher undrained strength.

Keywords: Deformation, index properties, organic soil, peat, shear strength

INTRODUCTION

Peat and organic soils commonly occur as extremely soft, wet, unconsolidated surficial deposits that are integral parts of the wetland systems. They may also occur as strata beneath other surficial deposits (Jarrett 1995). 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 (Hartlen and Wolski 1996). For the case of tropical peat, or tropical peat lands, the total world coverage is about 30 million hectares, two thirds of which are in Southeast Asia. Malaysia has some 3 million hectares - about 8% of the land area is covered with tropical peat. While in Indonesia peat covers about 26 million hectare of the country land area, with almost half of the peat land total is found in Indonesia's Kalimantan.

Peat actually represents an accumulation of disintegrated plant remains, which have been preserved under condition of incomplete aeration and high water content. It accumulates wherever the conditions are suitable, that is, in areas with excess rainfall and the ground is poorly drained, irrespective of latitude or altitude. Nonetheless, peat deposits tend to be most 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 particular type of vegetation but also help preserve the plant remains.

These soils are generally referred to as problematic soils due to their high compressibility and low shear strength. Access to these superficial deposits are usually very difficult as the water table will be at, near or above the ground surface. Undoubtedly, these are the consequences of the tendency to either avoid construction and buildings on these soils, or when this is not possible, to simply remove, replace or displace them, that in some instances may lead to possibly uneconomical design and construction alternative. However in many countries including Malaysia, substantial areas are covered by this material. The thickness of this deposit varies from just about 1 m to more than 20 m thick. Pressures on the land use by industry, housing and infrastructure are leading to more frequent utilization of such marginal grounds. It is therefore necessary to expand the knowledge of their geotechnical properties and mechanical behavior, in particular those in relation to their deformation and shear strength

characteristics, and subsequently devises suitable design parameters and construction techniques on these materials.

Review of literature indicates that peat and organic soils are very variable in their properties, both from one deposit to another and from point to point in the same deposit. Such variations are associated with the origin of these soils, the type of plant from which they are derived, the mineral content of the deposit and the amount of decay or humification that had occurred. All these features are reflected in the mechanical behavior (compressibility and shear strength) with which the geotechnical engineer is concerned (Tresidder 1966). When a soil is subjected to an increase in compressive stress due to foundation load, the resulting soil compression (generally called settlement) generally consists of elastic compression (immediate settlement), primary compression (consolidation settlement) and secondary compression. Compared with mineral soils, peat soils are highly organic and highly compressible. Its compression or settlement process may take a considerably longer amount of time. Peat generally possesses low undrained strength and high compressibility. Buildings on peat are usually suspended on piles, but the ground around it may still settle, creating a scenario as depicted in Fig.1 below.

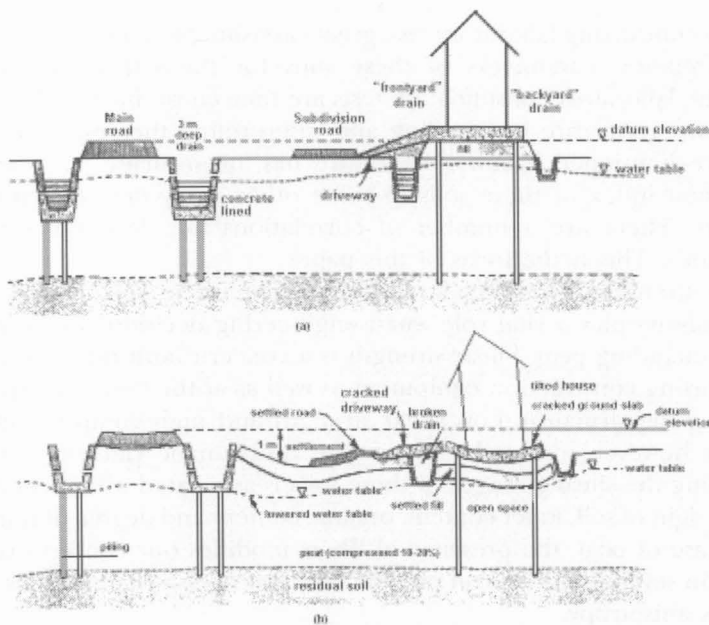


Fig. 1: (a) Typical section of a housing estate on peat (immediately after completion of construction) (b) Several years after completion of construction (scale exaggerated)

The calculation of the settlement requires evaluation of soil parameters from the compression curves which are usually obtained from laboratory oedometer tests. The results of incremental loading oedometer tests are usually

presented as the relationship between void ratio, e , and effective vertical stress, σ_v . The vertical effective stress may be plotted on a linear scale to determine the coefficient of volume change, m_v , and oedometer modulus, M , or on logarithmic scale to determine the compression index, c_c .

As with mineral soils (silt and clay), the settlement parameters of peat (i.e. consolidation settlement) may also be determined from standard incremental oedometer (one dimensional compression) tests (Edil 1997). The parameters are interpreted from traditional $e - \log \sigma_v$ plots. There may be differences in the magnitudes of various quantities measured but the general shape of the consolidation curves appear reasonably similar and the formulation developed for clay compression can be used to predict the magnitude and rate of settlement (Edil 1997).

There are however a certain class of peat, typically peat with high organic and fibre content with low degree of humification, that do not conform to the concept of conventional clay compression because of their different solid phase properties and microstructures. The analysis of compression of such materials present certain difficulties when conventional methods are applied because the curves obtained from the conventional oedometer tests and behaviour exhibited by them may show little similarity to the clay behaviour (Edil 1997; Den Haan 1997).

When conducting laboratory test, great care should be taken in determining the deformation parameters of these soils for the settlement calculations. Usually the laboratory consolidation tests are time consuming, rather expensive and require great care in handling and interpreting the results. Considering the above-mentioned factors, an effort has been made to correlate the compression index of these soils to some other easily determined soil index properties. There are a number of correlations for clays, but very few for organic soils. This is the focus of this paper.

Shear strength is another important parameter in soil mechanics. Shear strength always play a vital role when engineering decision comes across with any soils including peat. Shear strength is a concern both during construction for supporting construction equipment as well as at the end of construction in supporting the structure. Low shear strength and high compressibility of the peat soils however confined them in the problematic category. Accuracy in determining the shear strength of these soils is associated with several variables namely; origin of soil, water content, organic content and degree of humification. For the case of peat, the presence of fibers modifies our concepts of strength behavior in several ways. It can provide effective stress where there is none and it induces anisotropy.

Early research on peat strength indicates some confusion as to whether peat should be treated as a frictional material like sand or cohesive like clay. Commonly, surficial peats are encountered as submerged surficial deposits. Because of their low unit weight and submergence, such deposits develop very low vertical effective stresses for consolidation and the associated peat exhibit high porosities and hydraulic conductivities comparable to those of fine sand

or silty sand (Dhowian and Edil 1980). Such a material can be expected to behave "drained" like sand when subjected to shear loading. However, with consolidation, porosity decreases rapidly and hydraulic conductivity becomes comparable to that of clay. There is a rapid transition immediately from a well-drained material to an undrained material (Edil *et al.* 1994).

Determination of shear strength parameters for organic soils, as with other soils, is important and somehow a difficult job in geotechnical engineering. For organic soils, several methods have been used to determine the undrained shear strength in the laboratory namely Swedish fall-cone test, triaxial test, shear box test and vane shear test. For the case of field tests, field vane and Dutch Cone Penetration tests are often used.

TEST PROGRAMS

A series of laboratory and field test have been carried out to study the deformation and shear strength characteristics of tropical peat and organic soils.

For the study on deformation, samples were collected from nine different locations in the state of Johore, Perak, Sarawak and Selangor, generally at depth between 0.5 m – 1.0 m below the ground surface. The organic content of the samples range from 50 % to 95 %, with natural water content in the range of 200 % – 800 %, and liquid limit of 150 % to 400%. In terms of Van Post scale (Landva and Pheaney 1980), the samples were *H5* to *H9*, that is hemic to sapric peat. The consolidation characteristics of the samples were determined from standard incremental oedometer tests, with sample size of 75 mm diameter and 20 mm high, and applied normal stress of 5 kPa to 160 kPa. The consolidation parameters were interpreted from the traditional ϵ log σ_v plots.

For the study on shear strength, both laboratory and field tests were carried out. Several peat and organic soil samples were collected and tested for their undrained shear strength using laboratory shear box test with sample size of 60 mm x 60 mm by 25mm thick. The samples are generally obtained at depth of 0.5m below the ground level. In situ tests were also performed on the same site using a small (50 mm diameter) field vane shear at depth of about 0.5 m below ground surface. The samples were collected from five different locations in Selangor and Negeri Sembilan. The organic content of the sample range from 79 % – 98 %, with liquid limit of 160 % – 377 %, and water content of 200 % - 800 %. In order to examine the effect of degree of humification on the soil shear strength, tests were done on samples with Van Post scale (Landva and Pheaney 1980) ranging from *H1* to *H10*, that is from fibric to hemic to sapric peat.

TEST RESULTS AND DISCUSSION

Deformation Characteristics

(i) Compression Index, c_c and Liquid Limit, w_L

An effort is made to correlate compression index, c_c , with liquid limit, w_p void ratio, e_o , and ratio of $c_c / (1+e_o)$.

The plot of compression index, c_c , versus the liquid limit of the soil shows that c_c increases with the liquid limit (w_L) of the soil as shown in Fig. 2. Farrell *et al.* (1994) considered the empirical relationship between the compression index and the liquid limit suggested by Skempton and Petley (1970) for organic soils (equation 1) as to give a reasonable approximation of this parameter. Hobbs (1986) estimated the compression index for fen peat using equation 2, which gave a slightly lower value of c_c . Values of c_c of tropical peat samples tested however were apparently a little higher than the above two relationships (Fig. 2).

$$c_c = 0.009(w_L - 10) \tag{1}$$

$$c_c = 0.007(w_L - 10) \tag{2}$$

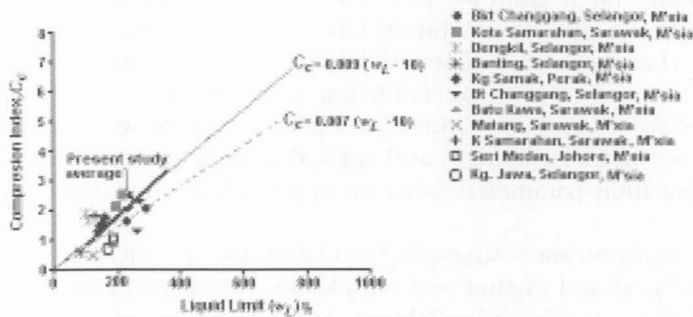


Fig. 2: Compression index (c_c) versus liquid limit (w_L)

The c_c values of the tropical peat studied range from 1 to 3, much higher than sedimentary soil such as clay whose c_c is only 0.2 – 0.8. It is of interest to note that the c_c of the Irish peat range from 1 – 4, as shown in Fig. 3, which is quite close to the tropical peat.

Azzouz *et al.* (1976) reported the following relationship for organic soil and peat,

$$c_c = 0.0115 w \tag{3}$$

Where w is soil natural water content in percent. Note that the natural water content of the peat studied range from 200 % – 800 %. Using the above equation, this would give c_c of 2 – 9, which is higher than the measured values.

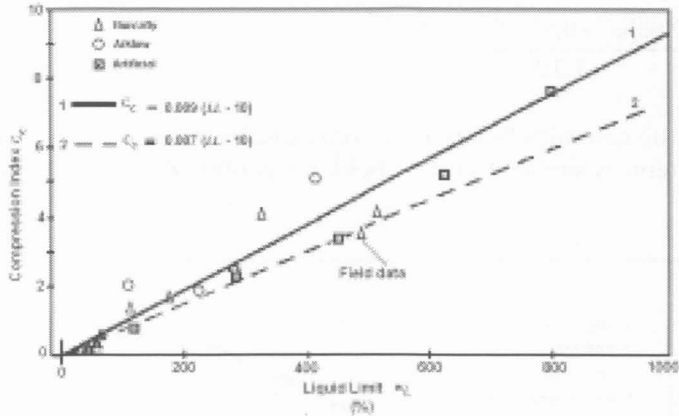


Fig. 3: Compression index (c_c) - liquid limit (w_L) (Farrel et al. 1994)

(ii) Void Ratio with Liquid Limit and Natural Water Content

Fig. 4 shows a plot of the initial void ratios versus liquid limits of the peat and organic soils from several sites in Malaysia together with the normally consolidated peat found by Miyakawa (1960), and Skempton and Petley (1970). The figure shows an increasing trend in void ratio with the increase of the soil liquid limits. Void ratio of the tropical peat studied is found to range from 1.5 – 6, that is

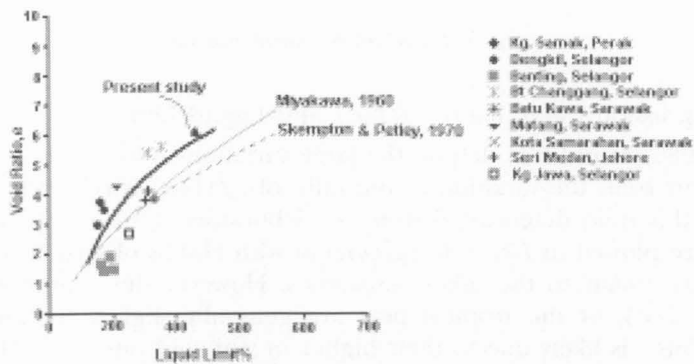


Fig. 4: Relationship between the void ratio and liquid limit

for the case of amorphous peat. For the case of fibrous peat it can be as high as 25. Such high void ratios gives rise to phenomenally high water contents. For comparison, Malaysian marine clay for instance, has an initial void ratio in the range of 1.5 to 2.5. The natural void ratios of the peat indicate their higher compressibility.

Fig. 5 shows the graph of void ratio (e_0) and natural water content (w_0). The best-fit line in the above figure is expressed by:

$$e_o = \frac{30.65(w_o + 0.88)^{0.116} - 30}{1.12} \quad (4)$$

As for the case with liquid limit, void ratio increases with increase in natural water content. A similar trend of behavior is observed by Den Haan (1997).

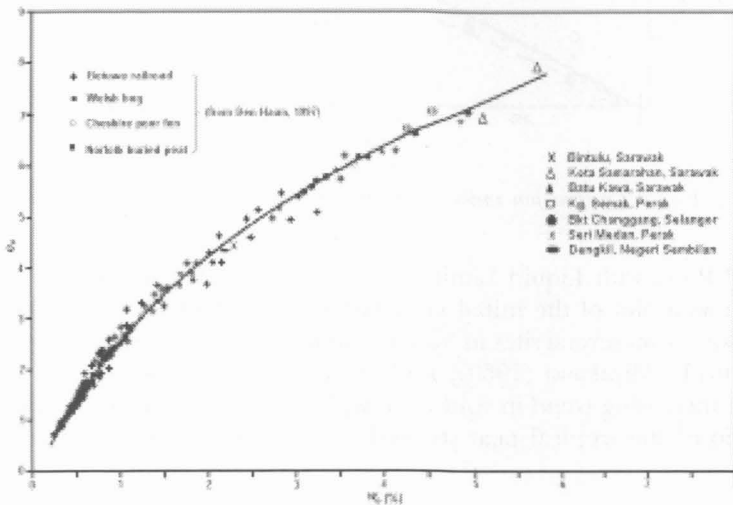


Fig. 5: Initial water content-void ratio

(iii) Compression Index Ratio, $c_c/(1+e_o)$, and Liquid Limit

Hobbs (1986) found that despite the large variations, which occur within peat and organic soils, the variation in the ratio of $c_c/(1+e_o)$ is relatively small. The values of this ratio determined from the laboratory test on tropical peat soil samples are plotted in Fig. 6. In agreement with Hobbs observation, the trend obtained is similar to the other researches. However the compression index ratios, $c_c/(1+e_o)$, of the tropical peat are generally slightly higher than the others. This is likely due to their higher in situ void ratio (e_o). The value of e_o depends on the in situ vertical stress; hence e_o must be that appropriate to the very low effective stress conditions.

Shear Strengths of Tropical Peat and Organic Peat Soil

(i) Shear Box Test

The results obtained from the shear box tests are shown in Table 1. The results show that the shear strengths of the peat and organic soils are very low. From the shear box test, it was found that the soils have low cohesion, (c_u), with values in the range of 6 to 17 kPa. The angle of internal friction, (ϕ_u), ranges from 3° to 20°. The ϕ_u values are generally lower with increasing degree of humification.

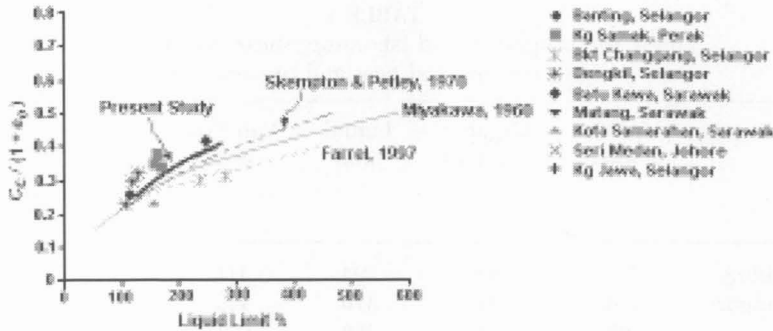


Fig. 6: Relationship between $c/(1+e_0)$ and the liquid limit

Similar trend is also observed for cohesion. A typical normal and shear stresses plot of the shear box test is shown in Fig. 7.

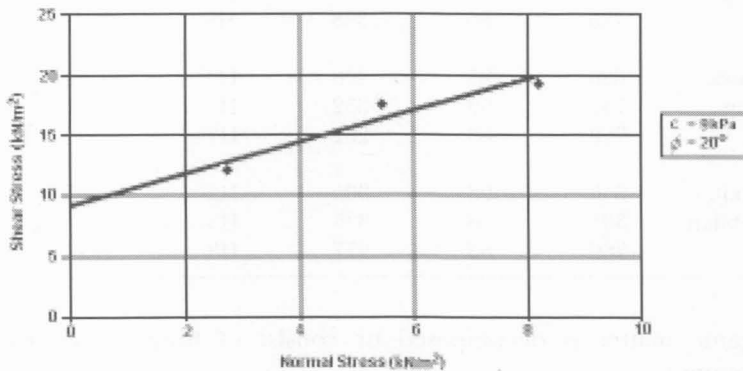


Fig. 7: Typical relationship between shear stress and normal stress for sample with high fibrous content (H1) (sample location: Banting, Selangor, Malaysia)

(ii) Field Vane Test

From the vane shear test, the undrained strength of the soils were found to range from 3 kPa -15 kPa (Table 2).

The plot of moisture content against vane shear strength portrays a decreasing behaviour of shear strength with increasing moisture content, as shown in Fig. 8. At the same moisture content, the high fibrous (H1-H3) peat gives higher strength compared with the medium and low fibrous (H4-H10) peat. In general, the high fibrous or fibric (H1 - H3) peat has higher shear strength than the medium fibrous or hemic (H4 - H6) peat and the low fibrous or sapric (H7 - H10) peat. The behaviour is more or less the same when vane shear strength is plotted against organic content, Fig. 9. According to Mitchell (1993), the effect of organic matter and stiffness of soils depends largely on whether

TABLE 1
Basic soil properties and laboratory shear box test results
of some tropical peat and organic soils

| Location | Moisture content | Organic content | Liquid limit | Van Post scale | Cohesion (kPa) | Angle of internal friction (deg) |
|-------------------------|------------------|-----------------|--------------|----------------|----------------|----------------------------------|
| Banting, Selangor | 211 | 85 | 294 | H1 | 9-11 | 9-20 |
| | 219 | 94 | 316 | H6 | 11-12 | 9-12 |
| | 802 | 83 | 362 | H10 | 6-10 | 12-20 |
| Banting, Selangor | 195 | 79 | 219 | H2 | 6-11 | 9-16 |
| | 832 | 84 | 361 | H5 | 8-10 | 7-10 |
| | 225 | 85 | 166 | H8 | 8-12 | 6-11 |
| Kg. Jawa, Klang | 215 | 78 | 180 | H3 | 10-12 | 6-14 |
| | 209 | 89 | 325 | H6 | 12-14 | 7-25 |
| | 786 | 85 | 368 | H8 | 7-11 | 8-13 |
| Kg. Jawa, Klang | 680 | 85 | 298 | H3 | 11-12 | 10-15 |
| | 747 | 93 | 352 | H5 | 10-12 | 5-10 |
| | 720 | 83 | 282 | H7 | 7-9 | 9-12 |
| Dengkil, N. Sembilan | 246 | 98 | 305 | H2 | 13-17 | 3-12 |
| | 301 | 98 | 335 | H5 | 11 | 13-15 |
| | 786 | 83 | 377 | H8 | 8-9 | 12-20 |

the organic matter is decomposed or consist of fibres which can act as reinforcement.

According to Van Post scale (Landva and Pheeny 1980), the degree of humification is graded on scale from 1 to 10 and designated from *H1* to *H10*. *Fig. 10* shows the decreasing trend between the degree of humification and the vane shear strength. The shear strength obtained from vane shear strength test decreases gradually with high degree of the humifications.

Fig. 11 shows the field vane shear data, measured with the larger (100 mm diameter) vane, from a new mosque project site at Putrajaya, Malaysia. There is only a slight tendency for an increase in strength with depth. The low bulk density of peat together with high water table implies low effective stresses with depth. Because of this there may not be a discernible increase of strength with depth within the peat layer (0.5 m – 4.0 m).

The field vane shear strength seems to relate well with results obtained using the small vane shear, for soil with a similar degree of humification as shown in *Fig. 10* above.

Yogeswaran (1995) reported the average field vane shear strength for tropical peat found in Sarawak to be only 10 kPa while the sensitivity ranges

TABLE 2
Basic properties and vane shear strength parameters
of some tropical peat and organic soils

| Location | Moisture content | Organic content | Liquid limit | Van Post scale | Field vane shear strength (kPa) |
|----------------------|------------------|-----------------|--------------|----------------|---------------------------------|
| Banting, Selangor | 211% | 85% | 294% | H1 | 10 - 12 |
| | 219% | 94% | 316% | H6 | 7 - 9 |
| | 802% | 83% | 362% | H10 | 4 - 6 |
| Banting, Selangor | 195% | 79% | 219% | H2 | 11 |
| | 832% | 84% | 361% | H5 | 10 |
| | 225% | 85% | 166% | H8 | 4 |
| Kg. Jawa, Klang | 214% | 79% | 180% | H3 | 11 |
| | 225% | 84% | 325% | H6 | 8 |
| | 618% | 88% | 368% | H8 | 5 |
| Kg. Jawa, Klang | 680% | 85% | 298% | H3 | 10 - 15 |
| | 747% | 93% | 352% | H5 | 5 - 10 |
| | 720% | 83% | 282% | H7 | 9 - 12 |
| Dengkil, N. Sembilan | 246% | 98% | 305% | H2 | 9 - 13 |
| | 301% | 98% | 335% | H5 | 6 - 10 |
| | 786% | 83% | 377% | H8 | 3 - 6 |

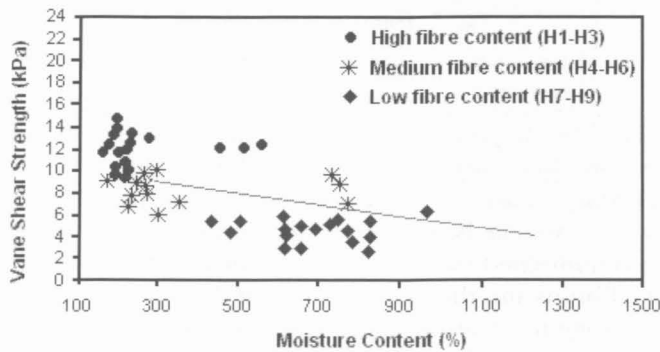


Fig. 8: Plot of vane shear strength versus moisture content

the degree of humification of the soils, with more fibrous soils having higher undrained strength.

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