

**EFFECT OF ORGANIC CONTENTS ON THE COMPACTION AND SHEAR  
STRENGTH OF SOIL**

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## **ABSTRACT**

The present project is aimed at studying the effects of organic content on the soil geotechnical characteristics mainly compaction and shear strength. In this project, peat soil is treated as organic content, which is added to silty soil in different percentages by weight. The amount of peat added was on the basis of mass replacement. The standard Proctor test and vane shear test were conducted to determine the compaction and strength of these soil mixtures. The results of Proctor tests for these soil mixtures reveal that the maximum dry density decreases approximately 28% as the organic content in silty soil increases by 40%. However, the optimum moisture content (OMC) increases by approximately 109% as the organic content in silty soil increases by 40%. The vane shear test results reveal that the shear strength of soil mixtures decreases as the organic content in silty soil increases. Therefore, minimization of organic content in soil is important to ensure maximum soil strength for constructions especially on peaty soils; as peaty soils are widely distributed in Sarawak.

## ABSTRAK

Projek ini adalah bertujuan untuk mengkaji kesan kandungan organik terhadap sifat geoteknikal tanah terutamanya mampatan dan daya ricih. Dalam projek ini, tanah gambut dianggap sebagai kandungan organik yang akan dicampurkan kepada tanah silt dalam peratusan berat yang berlainan. Kandungan tanah gambut yang dicampur adalah berdasarkan kaedah penggantian jisim. Ujian Proctor dan ujian ricih vane telah dijalankan untuk mengkaji mampatan serta daya ricih campuran-campuran tanah. Keputusan ujian Proctor terhadap campuran-campuran tanah menunjukkan bahawa ketumpatan kering maksimum semakin berkurangan sebanyak 28% dengan pertambahan kandungan organik sebanyak 40%. Walaubagaimanapun, kandungan lembapan optimum (OMC) bertambah sebanyak 109% dengan pertambahan kandungan organik sebanyak 40%. Keputusan ujian ricih vane menunjukkan bahawa daya ricih campuran-campuran tanah semakin berkurangan dengan pertambahan kandungan organik. Oleh yang demikian, pengurangan kandungan organik dalam tanah adalah penting agar kekuatan maksimum tanah dapat dicapai untuk tujuan pembinaan terutamanya pembinaan di kawasan bertanah gambut yang juga merupakan kawasan tanah yang didapati secara meluas di Sarawak.

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# CHAPTER 1

## INTRODUCTION

Peat and organic soils commonly occur as extremely soft, wet, unconsolidated surficial deposits that are integral part of wetland systems (Jarret, 1995). Sarawak has the largest peat area in Malaysia with 16,500 km<sup>2</sup> that makes up 13% of the state, of which about 90% is more than 1 m in depth. The essential aspect to note is that peat here is identified from the soil sciences perspective prior to 1982 where soil with more than 35% of organic matter content were described as peat and this will be seen later differs from the geotechnical perspective. Another point to take heed of here is that the thicknesses of some of these peat deposits are too shallow to be of any impendence to construction (Singh et al., 1997).

Tropical peat in Sarawak is in general non-homogenous. The overall hydrological characteristic depends on the rainfall and the surface topography. Peat land is sometimes known as wetland because of the high depth of water table, which is sometimes even higher than the peat surface. Peat has very high moisture content and capacity to hold water, making it very buoyant and high in pore volume. These characteristics are the main cause of peat to have low bearing capacity and bulk density (Singh et al., 1997).

Most of the peat are found on the coastal lowlands and form a corridor parceling the coast. The peat in these coastal lowlands lies between the lower stretches of the main river courses. Some small pockets of peat also occur in poorly drained interior valleys. The former are referred to as 'basin peat' while the later is

called 'valley peat'. In fact, at one time the peat or organic soils (as they were equivalent terms then) were divided on the basis of their place of occurrence into basin and valley peat. Geographically, these peats are found in the administrative divisions of Kuching (23 059 km<sup>2</sup>), Kota Samarahan (192 775 km<sup>2</sup>), Sri Aman (283 076 km<sup>2</sup>), Sibü (540 800 km<sup>2</sup>), Sarikei (169 900 km<sup>2</sup>), Bintulu (146 121 km<sup>2</sup>), Miri (276 579 km<sup>2</sup>) and Limbang (25 300 km<sup>2</sup>) on their coastal side in Sarawak with a total area of 1 657 600 km<sup>2</sup>.

Organic matter in soils consists of a complex mixtures of plant and animals remains decomposed to varying extents, substances synthesized by biological or chemical means from decomposition products. For this very complex system, organic matter is generally divided into two groups: nonhumic and humic substances (Schnitzer and Khan, 1972). Highly organic soils are defined as having organic content higher than 20%.

A problem with decomposing organics in fill is the developments of voids and the corresponding settlement. The rate of settlement will depend on how fast the nonhumic substances decompose, and the compression characteristics of the organics (Das, 1994). In this project an attempt has been made to study the effect of organic content and on its engineering properties mainly the compaction and shear strength characteristics.

Several researchers have studied the engineering behaviour of peat soil but there is not much studies available on the effect of very small percentages of organic content on the behaviour of engineering properties mainly compaction and shear strength characteristics. This study is very important to check the maximum dry density and shear strength for constructions especially on peaty soils; as peaty soils are widely distributed in Sarawak.



# CHAPTER 2

## LITERATURE REVIEW

### 2.1 General

A review of existing literature on the effects of organic contents mainly on compaction and shear strength characteristics of the soil has been discussed in this chapter. The first part of the literature review deals with the physical characteristics and index properties of organic soil (peat) and the second part describe the compaction and shear strength properties of peat.

### 2.2 Physical characteristics of organic (peat) soil

#### 2.2.1 *Degree of Decomposition*

Peat soil tends to become more decomposed as decay occurs. The degree of peat decomposition is expressed by using the Von Post decomposition scale, which was developed by Von Post and Granlund in 1926. Table 2.1 postulates the Von Post decomposition scale, which is the most widely used to determine the degree of decomposition of peat soil (Liang, 1998). The degree of decomposition is termed as the H-value with a scale ranging from H1 to H10. H1 indicates the least decomposed, herbaceous peat; meanwhile H10 indicates the most decomposed, amorphous peat. For geotechnical purposes, Edil (2003) has stated that according to Magnan, 1980 (ASTM Standard D 5715), this degree of decomposition, from H1 to H10, is reduced

to three main classes to simplify them for geotechnical purposes. They consist of the followings:

- a) Fibric or fibrous (least decomposed), tentatively ranging from H1 to H3.
- b) Hemic or semi-fibrous (intermediate), tentatively ranging from H4 to H6.
- c) Sapric or amorphous (most decomposed), tentatively ranging from H7 to H10.

**Table 2.1 Von Post Degree of Decomposition scale (after Von Post and Granlund, 1926)**

<b>Degree of humification</b>	<b>Description</b>
H1	Completely undecomposed peat which release 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 materials present.
H3	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 materials present.
H4	Slightly decomposed peat which releases very muddy dark water. No peat is passed between the fingers but the plant remains are slightly pasty and have lost some of the identifiable features.
H5	Moderately decomposed peat which releases very “muddy” water with also a very small amount of amorphous granular peat escaping between the fingers. The structure of plant remains is quite indistinct, although it is still possible to recognize certain features. The residue is strongly pasty.
H6	Moderately strongly decomposed peat with a very indistinct plant structure. When squeezed, about one – third of the peat escapes between the fingers. The residue is strongly pasty but show the plant structure more distinctly than before squeezing.
H7	Strongly decomposed peat. Contains a lot of amorphous material with very faintly recognizable plant structure. When squeezed, about one – half of the peat escapes between the fingers. The water, if any is released, is very dark and almost pasty.

H8	Very strongly decomposed peat with a large quantity of amorphous material and very dry 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, almost all of the peat escapes between the fingers as a fairly uniform paste.
H10	Completely decomposed peat with no discernible plant structure. When squeezed, all the wet peat escapes between the fingers.

### 2.2.2 Organic Content (OC) and Loss-on-Ignition (LOI)

The organic matter of peat is generally combustible carbonaceous matter. Soil organic matter has been defined as "...a whole series of products which range from un-decayed plant and animal tissues through ephemeral products of decomposition to fairly stable amorphous brown to black material bearing no trace of the anatomical structure of the material from which it was derived; and it is this latter material that is normally defined as the soil humus" (Russell, 1952). Additionally, soil organic matter also contains products of microbial synthesis. In summary soil organic matter includes:

- (i) fresh plant and animal residues (decomposable),
- (ii) humus (resistant),
- (iii) inert forms of nearly elemental carbon (charcoal, coal, or graphite).

For classification of peat, the most common system is based solely on organic content. According to the American Society for Testing Materials (ASTM) for classifying peat and organic soil and it is shown as follows:



- (i) OC < 5%: little effect on behavior, considered as inorganic soil
- (ii) OC = 6 – 20%: effects properties but behavior is still like mineral soil, organic silt and clay.
- (iii) OC = 21 – 74%: organic matter governs properties; traditional soil mechanics may be applicable, silty or clayey organics.
- (iv) OC > 75%: displays behavior distinct from traditional soil mechanics especially at low stresses; peat.

Carbon is the chief element of soil organic matter that is readily measured quantitatively by combustion (herein C is determined as CO<sub>2</sub> emitted). The organic carbon content may be used to estimate total organic matter by multiplying the figure for organic carbon by a factor of 1.724 or somewhat higher figures up to 2. Alternatively, ignition of the soil at high temperature (440 to 550°C) to achieve destruction of organic matter can be used to determine organic content directly.

The loss-on-ignition (LOI) method gives quantitative oxidation of organic matter, but because it may decompose some of the inorganic constituents of the soil, it may give a number in excess of the actual organic content. The soil organic matter, when extracted, can be fractionated into components, primarily those characteristic of plant tissues and those based on humus. The first group (nonhumic matter) includes fats, waxes, oils, resins, water-soluble polysaccharides, hemicelluloses, cellulose and protein. The second group includes humus fraction consisting of basically humic and fulvic acids and humin and exists both in solid and liquid phases (Huttunen et al. 1996)

### 2.2.3 *Specific Gravity( $G_s$ )*

The specific gravity of solids in peat and organic soils is greater than 1 and increases with increasing mineral content. In the literature the range of specific gravities is from 1.1 to 2.5 for peat (Muskeg Engineering Handbook, 1969) and it could be slightly higher for some organic soils with low organic content. An approximate and easier method of determining specific gravity is to use ash content or organic content (loss on ignition) assuming that the ash is composed of clay minerals with specific gravity of 2.7 and the organic matter has a specific gravity of 1.5 (Cook, 1956). The average specific gravity of soil solids is then calculated from:

$$G_s = 2.7 (1 - OC) + 1.5 OC$$

where, OC is the organic content or loss on ignition. This assumption may lead to an error of as high as 18% (Doyle, 1963).

Alternatively, specific correlations between specific gravity and LOI or OC can be developed experimentally for a given organic deposit (Skempton and Petley, 1970; Den Haan and El Amir, 1994). Den Haan and El Amir (1994) have reported that the close correlation between these parameters including clays and peat from different locations in the Netherlands. Their relationship is given by:

$$1/G_s = OC/1.365 + (1-OC)/2.695$$

Their values of specific gravity are somewhat lower than given by Skempton and Petley (1970) and Cook (1956).

#### **2.2.4 Unit Weight**

Due to lower specific gravity of solids found and higher water holding capacity, unit weight of peat and organic soils is typically lower compared to inorganic soils. Saturated unit weights ( $\gamma_{\text{sat}}$ ) vary from about 10 to 18 kN/m<sup>3</sup> as a function of organic content, i.e., loss on ignition decreasing from 90% to 5%.

Dry unit weight also decreases as a function of initial water content; empirical correlations have been proposed by various investigators based on their test results as reported by Den Haan and El Amir (1994).

### **2.3 Index properties of organic (peat) soil**

#### **2.3.1 Atterberg Limits**

The concept of Atterberg limits for a soil is related to the amount of water that is attracted to the surfaces of the soil particles. Surface area increases per unit mass with the decreasing particle size, it may be expected that the amount of water attracted will be largely influenced by the amount of clay present in the soil.

Hobbs (1986) studied the relationships between water content ( $w$ ) and the liquid limit ( $w_L$ ) as shown in Fig. 2.1. He found that the water content of the tropical organic soils was about 1.67  $w_L$ . This is higher than the Fen peat reported by where  $w$  is about 0.85  $w_L$  (Farrell, 1998).



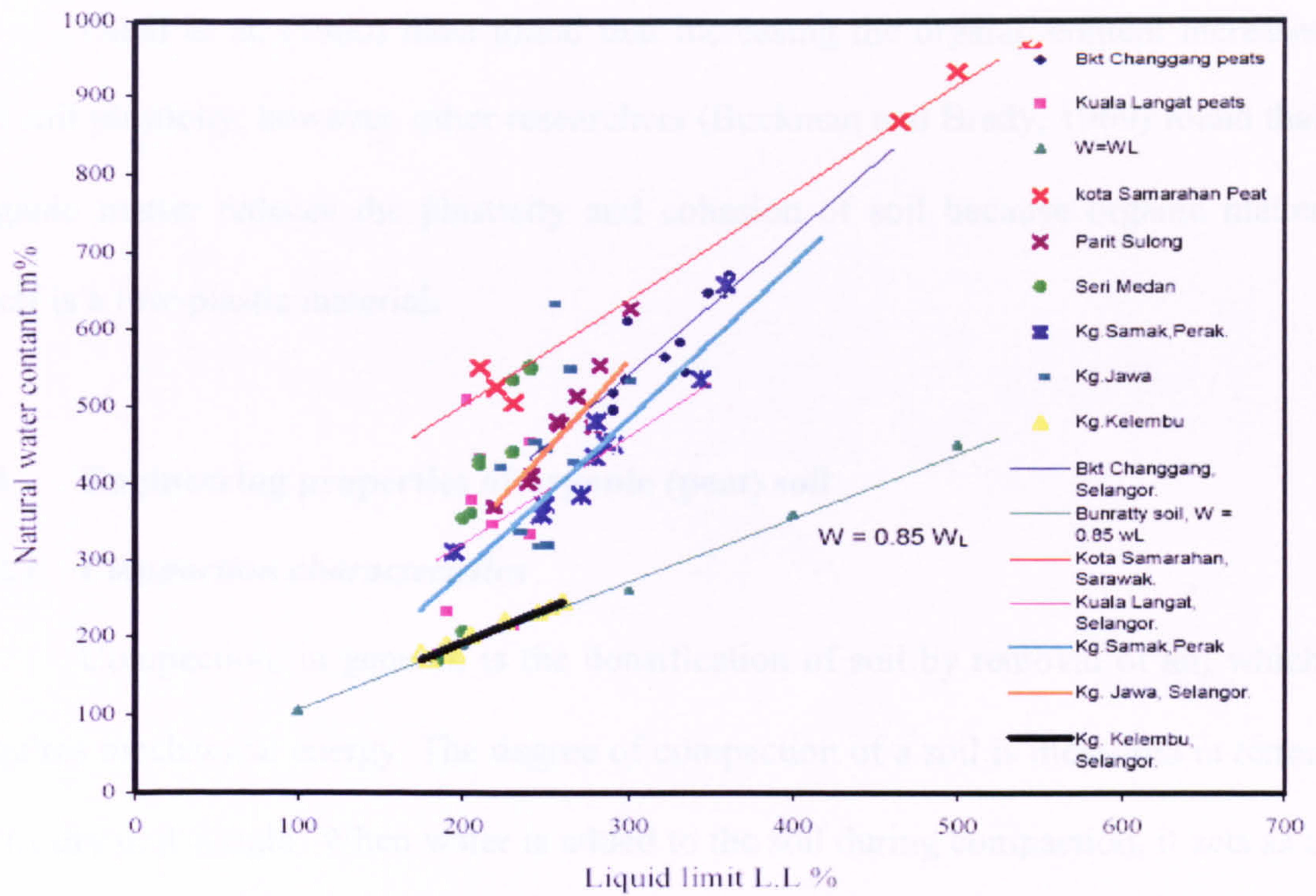


Figure 2.1 Water content ( $w$ ) versus liquid limit ( $w_L$ )

Empirical relationships between organic content ( $H$ ) and liquid limit ( $w_L$ ) have been proposed by Skempton and Petley (1970); Miyakawa (1960) and Farrell (1998) as shown in Figure 2.2.

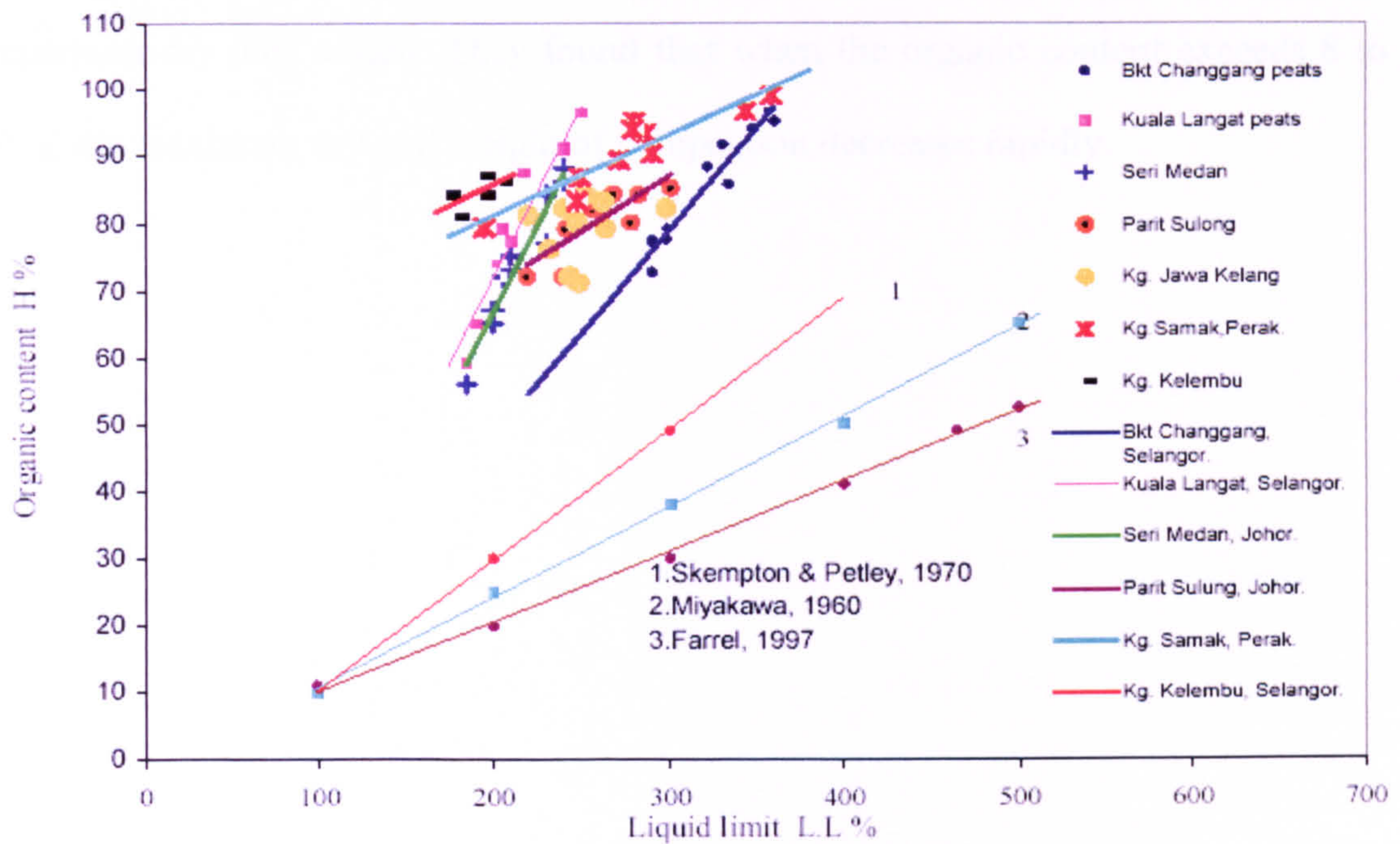


Figure 2.2 Organic content ( $H$ ) versus liquid limit ( $w_L$ )



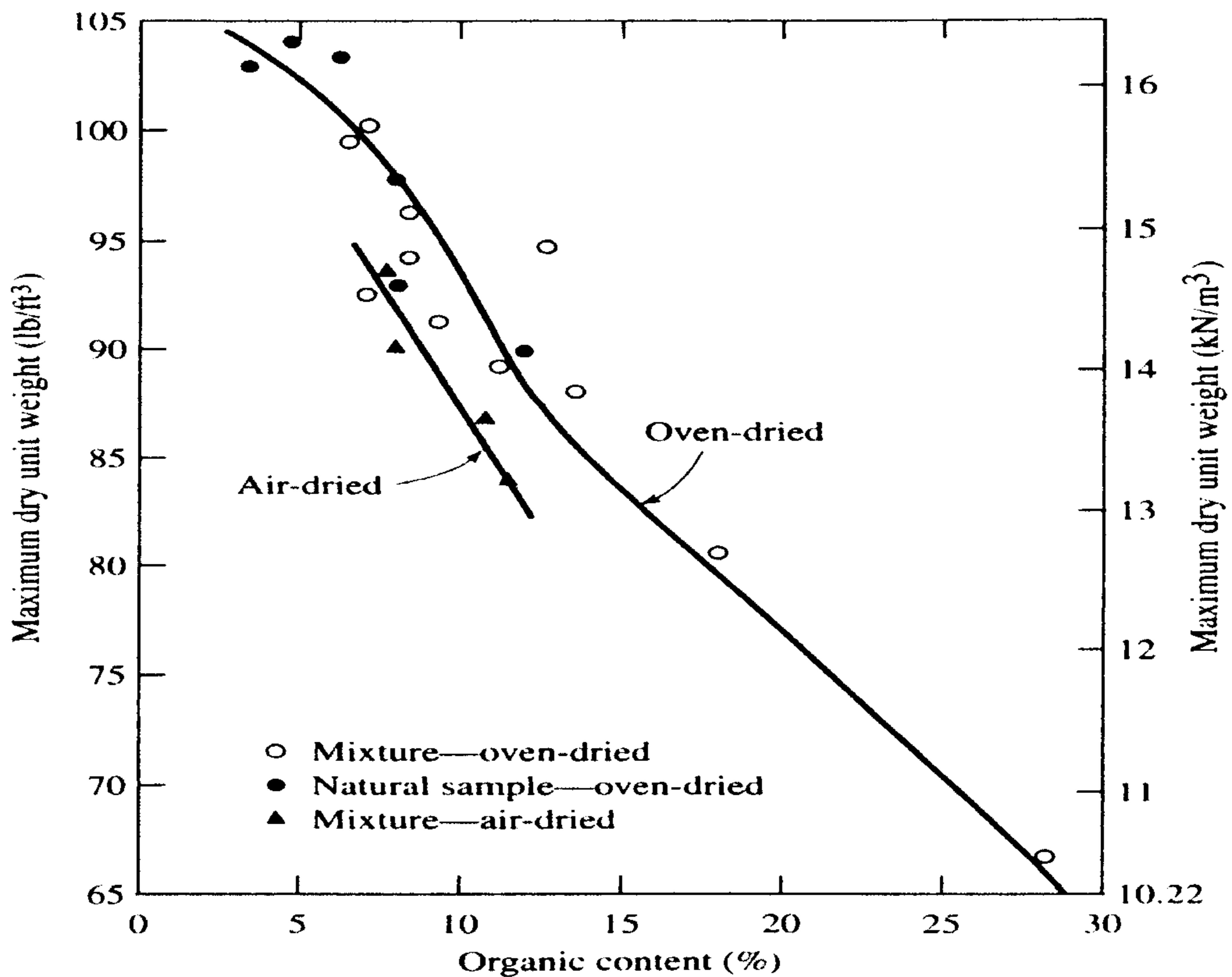
Odell et al. (1960) have found that increasing the organic content increases the soil plasticity; however, other researchers (Buckman and Brady, 1969) found that organic matter reduces the plasticity and cohesion of soil because organic matter itself is a low-plastic material.

## **2.4 Engineering properties of organic (peat) soil**

### **2.4.1 *Compaction characteristics***

Compaction, in general, is the densification of soil by removal of air, which requires mechanical energy. The degree of compaction of a soil is measured in terms of its dry unit weight. When water is added to the soil during compaction, it acts as a softening agent on the soil particles. The soil particles slip over each other and move into a densely packed position.

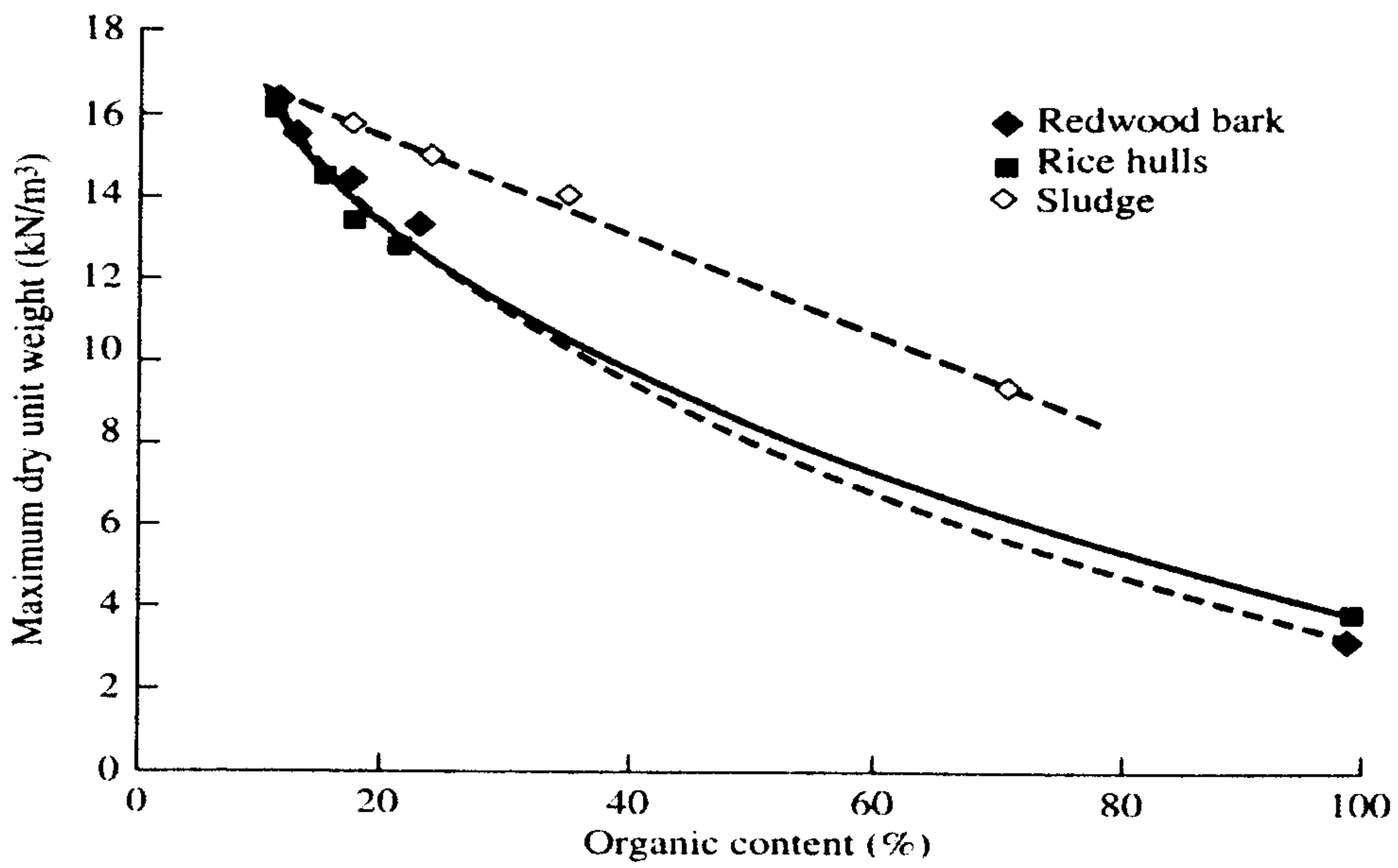
Franklin et al., (1973) conducted several laboratory tests to observe the effect of organic content on the compaction characteristics of mechanical mixtures of organic soils and peat. Figure 2.3 shows the effect of organic content on the maximum dry unit weight. They found that when the organic content exceeds 8 to 10%, the maximum dry unit weight of compaction decreases rapidly.



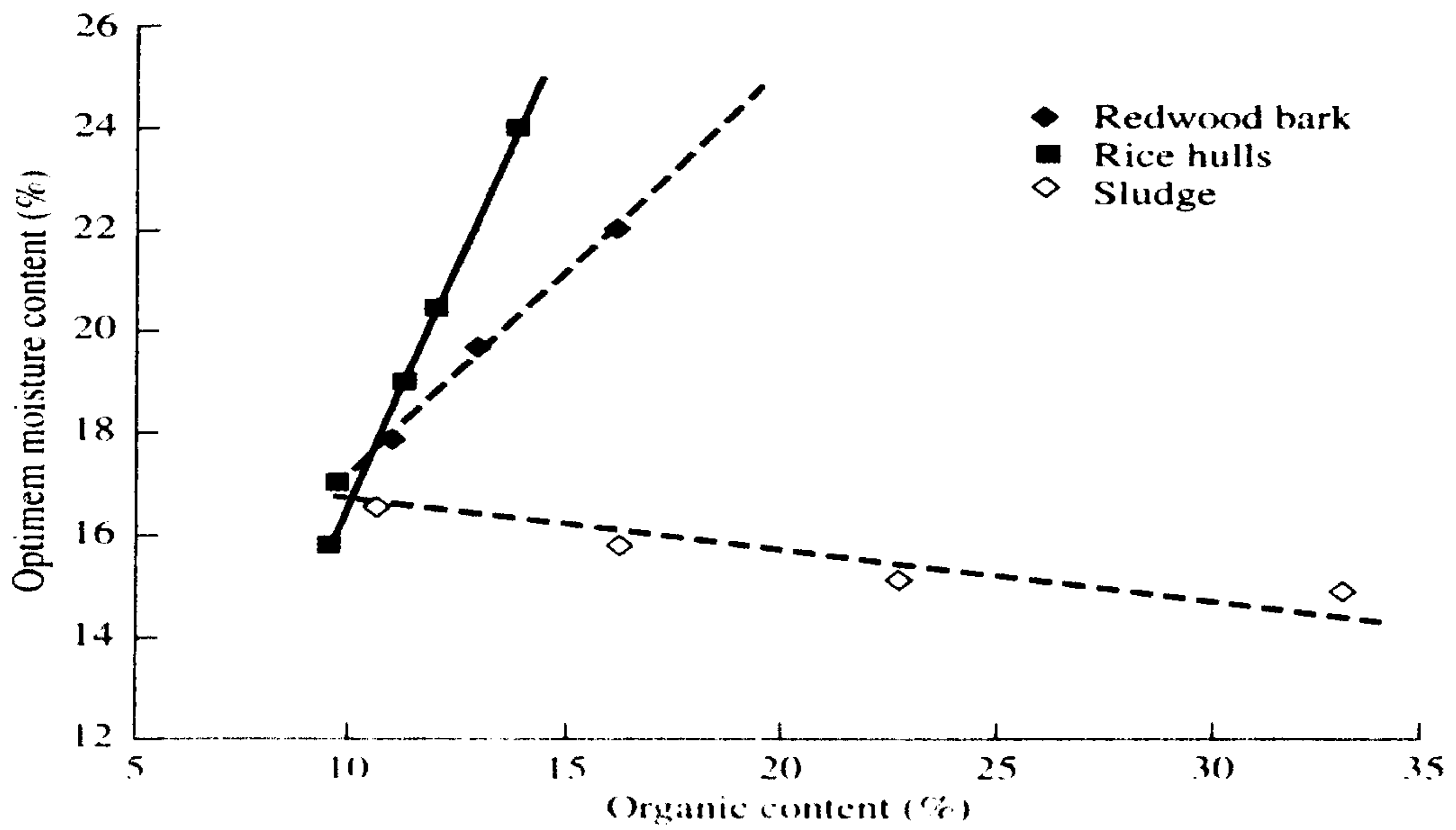
**Figure 2.3 Variation of maximum dry unit weight with organic content (after Franklin et al., 1973)**

Lancaster et al. (1996) conducted several modified Proctor tests to determine the effect of organic content on the maximum dry unit weight and optimum moisture content of soil and organic material mixtures. The soils tested consisted of a poorly graded sandy soil (SP-SM) mixed with either shredded redwood bark; shredded rice hulls, or municipal sewage sludge. Figures 2.4 and 2.5 and show the variations of maximum dry unit weight of compaction and optimum moisture content, respectively, with organic content. As in Figure 2.4, the maximum dry unit weight decreased with organic content in all cases. Conversely, the optimum moisture content increased with organic content for soil mixed with shredded redwood or rice hulls (Figure 2.5), similar to the pattern shown in Figure 2.5. However, for soil and municipal sewage sludge mixtures, the optimum moisture content remained practically constant (Figure 2.5).





**Figure 2.4** Variation of maximum dry unit weight of compaction with organic material mixtures (after Lancaster et al., 1996)



**Figure 2.5** Variation of optimum moisture content with organic content – soil and organic material mixtures (after Lancaster et al., 1996)

Holtz and Krizek (1970) have studied the behaviour of organic content in compaction properties and found that the maximum dry density of compaction decreased with increasing organic content.

#### **2.4.2 *Shear strength characteristics***

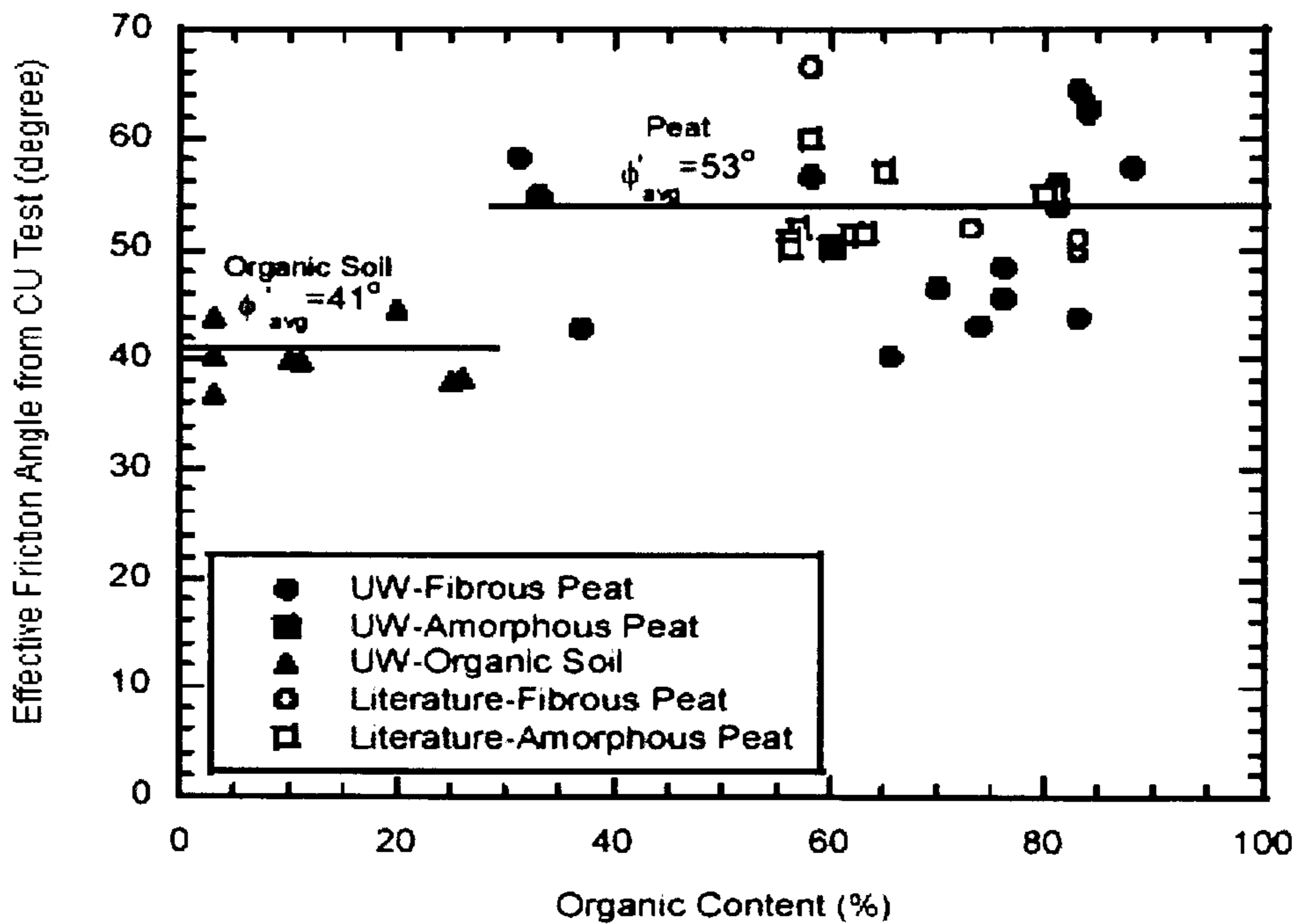
Shear strength is a fundamental property required in the analysis of construction projects over peat and organic soils and it generally has a limiting low value for such soils. Shear strength is a concern both during construction for supporting construction equipment as well as at the end of construction in supporting the structure. Peat, due to fibrous organic content, presents a distinct behavior than inorganic soils. 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. It also results in reduced  $K_0$  values compared to clays (Edil and Dhowian, 1981).

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. 1991 and 1994a).

Effective friction angle ( $\phi$ ) of peat is typically determined in consolidated undrained (CU) triaxial compression tests and occasionally in drained direct, ring or simple shear tests. Drained triaxial tests are seldom performed due to gross change in specimen dimensions and shape during the test. Normally consolidated peat exhibit zero or small effective cohesion and generally high effective friction angles.

Edil and Wang (2000) have reported that the effective friction angle is a function of organic content based on the extensive database available at the University of Wisconsin, USA (Figure 2.6).

In this figure, those materials with an organic content less than approximately 25% are called organic soils and more than 25% to designate the material "peat." The fibrous and the amorphous peat show no perceptible differences. Fiber content measurements were available except for only a few of the samples; therefore, these designations are based on visual observations or on reports (for those obtained from the literature). There is significant dispersion of the data with most of the data falling between  $40^\circ$  and  $60^\circ$ . The average effective angle of friction is  $53^\circ$  for the peat and clearly above the average angle of  $41^\circ$  for the organic soils.



**Figure 2.6 Effective friction angle versus organic content**

There is clear evidence that peat have extraordinarily high effective friction angles based on CU triaxial compression tests compared to most inorganic soils. There are not many direct shear, ring shear or direct simple shear data available. The effective friction angles averaged  $33^\circ$  when tested in this manner compared to  $48^\circ$  in the corresponding triaxial compression tests.

Landva and La Rochelle (1983) also reported  $32^\circ$  for a fibrous peat based on extensive ring shear testing compared to immeasurably high friction angles from a triaxial compression test on the same material.

Yamaguchi et al. (1985) and Farrell (1998) reported that lower friction angles in triaxial extension tests compared to triaxial compression tests.

Undrained strength is expressed as a normalized strength, i.e., ratio of undrained strength to vertical effective stress. Peat undrained strength is typically determined by vane shear in the field and by unconfined and consolidated undrained triaxial compression tests in the laboratory. Presence of fibers and their varying