Jurnal
Teknologi

Full Paper

ENGINEERING PROPERTIES OF PEAT IN OGAN ILIR REGENCY

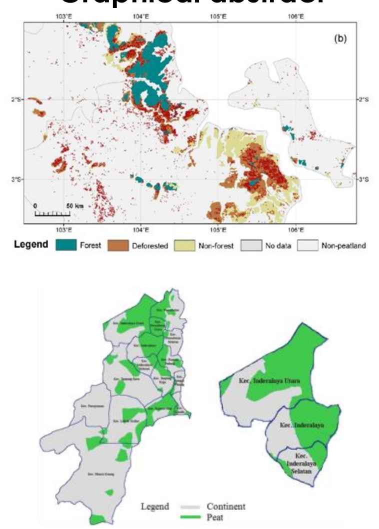
Yulindasari Sutejoa*[a], Ratna Dewi[a], Yulia Hastuti[b], Reffanda Kurniawan Rustam[b]

[a]Sriwijaya University, South Sumatera, Indonesia, Faculty of Civil Engineering
[b]PGRI University, South Sumatera, Indonesia, Faculty of Civil Engineering

Article history
Received
2nd December 2015
Received in revised form
13th March 2016
Accepted
31st March 2016

*Corresponding author
yulindasari@unsri.ac.id

Graphical abstract



Abstract

Seventeen percentages of Sumatra is covered with peat deposits. Some 1.6 million Ha is deposited in the East coast of South Sumatra. More over, 63.503 Ha is found in Ogan Ilir Regency. Laboratory soil tests are performed to determine the engineering properties of the peat. Generally the tests use undisturbed samples obtained with a block sampling from sites in Ogan Ilir Regency, but the physical tests for specific gravity, water content, and ignition loss occasionally employ disturbed samples. The tests for the determination of the engineering characteristics involve shear strength, consolidation, and permeability tests. The test results show that the peat soil in Ogan Ilir can be classified as fibrous peat with degree of decomposition (H_4–H_5 in von Post scale) and fiber content > 20 %. The average natural moisture content of the peat is 441,933 %. The average results of direct shear test showed the effective cohesion (c') and the effective angle of internal friction (ϕ') are 7.62 kPa and 19.93^0. The average coefficient of rate of consolidation (c_v) obtained from Oedometer test ranged from 3.20 from 0.93 for pressure range of 25 to 400 kPa. In general, the results show similar values with the reference data of other peat soils.

Keywords: fibrous peat; shear strength; consolidation; permeability

© 2016 Penerbit UTM Press. All rights reserved

1.0 INTRODUCTION

In Indonesia, peat covers about 26 million Ha of the country's land area. In fact, 17 % of Sumatra is covered with peat deposit. South Sumatera has a peaty area of 1.4 million Ha or 16.3 % of the area, and the condition is one of the natural resources that potential to be managed and utilized for the benefit and welfare of the entire community. In South Sumatera distribution of peat such as: OKI (500.000 Ha), Muba (250.000 Ha), Banyuasin (200.000 Ha), Muara Enim (45.000 Ha), Musi Rawas (35.000 Ha), and Ogan Ilir (63.503 Ha).

Peat commonly occurs as extremely soft, wet, unconsolidated superficial deposits normally as an integral part of wetland system [2]. Peat is generally found in thick layers in limited areas, and has low shear strength and high compressive deformations, this often results in difficulties when construction work is undertaken. Engineers try to avoid development over peat deposits whenever possible due to low shear strength and high compressibility as well as the difficulties encountered during construction.

There are two categories of peat deposit, i.e., the shallow deposit usually less than 3 m thick and the thickness of deep peat deposit exceeds 5 m. Generally, peat is grouped into two types; amorphous peat and fibrous peat. Amorphous peat is the peat soil with fiber content less than 20 %. While fibrous peat consists of fiber content more than 20 %. The behavior of amorphous granular peat is similar to clay soil. Fibrous peat contains two types of pores i.e.: macro-pores (pores between the fibers) micro-pores (pores inside the fiber itself). The behavior of fibrous peat is very different from clay due to the fiber in the soil.

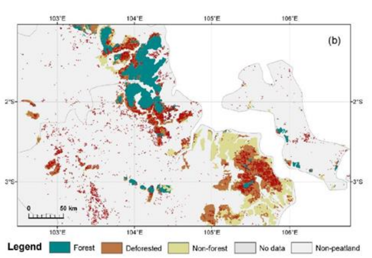
Replacing the peat with good quality soil is still a common practice when construction has to be erected on peat deposit even though most probably this effort will lead to uneconomic design. Approaches have been developed to address the problems associated with construction over peat deposits [3,4,8]. The selection of the most appropriate method should be based on the examination of the index and the engineering characteristics of the peat soil. The knowledge of the shear strength and the compression behavior is essential as it enables designers to understand the response of the soil to load and to suggest proper engineering solutions to overcome the problem.

This paper presents the results of the study of engineering properties of peat in Ogan Ilir Regency in terms of the physical and chemical propertis, shear strength, permeability, and compressibility behavior.

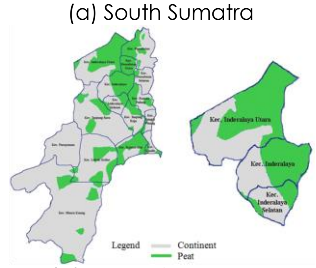
1.1 Ogan Ilir Regency, South Sumatra, Indonesia

Ogan Ilir regency has wide of region 2.666,07 km^2. Ogan Ilir regency represents one of the regency has the distribution of peat about 63.503 Ha (Ogan Ilir Regency Goverment, 2010). Inderalaya is a capital of in Ogan Ilir regency, South Sumatra. Wide of region district of Inderalaya is 101,22 km^2 consist of 13 sub-district.

Figure 1 shows the distribution of peat and soft soil deposit in South Sumatra and Ogan Ilir regency. The peat deposits form in depressions consisting predominantly of marine clay deposits or a mixture of marine and river deposits especially in areas along river courses. The thickness of the peat deposit varies from less than 100 cm to 400 cm, thus the peat deposit in South Sumatra is classified as shallow [7].



(a) South Sumatra



(b) Ogan Ilir Regency

Figure 1 Distribution of Peat Land and Soft Soil Deposit

1.2 Definition of Peat

In general, peat is a soil with high organic content, in cold and humid environments where dead hygrophytes have been deposited over a long period of time without fully decomposing. The term "peat" is borrowed from geology, and formerly meant vegetable matter in the early stage of coal formation. Peat is a mixture of fragmented organic material formed in wetlands under appropriate climatic and topographic conditions.

The peat soil is known for its low shear strength and high compressibility, which often results in difficulties when construction work has to take place on peat deposit. The low strength often causes stability problem and consequently the applied load is limited or the load has to be placed in stages. Large deformation may occur during and after construction period both vertically and horizontally, and the deformation may continue for a long time due to creep.

1.3 Sampling of Peat

There are two types of samples: disturbed and undisturbed samples. Disturbed samples can be used for identification purpose. Block sampling and piston sampler can be used to obtain samples at shallow depth [8]. For deeper elevation, screw augers, and split spoon sampler can provide disturbed sample. Undisturbed samples can be obtained at shallow depth by block sampling method, while large diameter tube sampler modified by adding sharp cutting edge may be used to obtain sample at depth. [9] claimed that both methods give good quality samples for obtaining engineering characteristics of peat.

Annual Book of ASTM Standard is standard practices for obtaining undisturbed block (cubical and cylindrical) samples of soils [10]. Undisturbed block samples are obtained from sites to determine the strength, consolidation, permeability, and other geotechnical engineering or physical properties of the undisturbed soil. These practices usually involve test pit excavation and are limited to relatively shallow depths. Figure 2 shows the procedure to the rectangular block sampling.

Landva attributed the disturbance during sampling to the loss of volume with the presence of gas, the loss of moisture, and the deformation of the peat structure. Large block samples (250 mm-square) can be obtained from below the ground and groundwater surface (down to a depth of 175 mm) using a block sampler for peat. Large-size down-hole block samplers such as Sherbrooke sampler (250-mm. in diameter) and Laval sampler (200-mm in diameter) that have been developed for sampling clays can also be used for organic soils and probably for peat [11].

[12] used block sampling method to obtain the samples of the fibrous peat from Kampung Bahru, Pontian, West Johore. The soil was excavated to a

depth of 1 m and then a tube of 300 mm-diameter and 300 mm high was pushed slowly into the soil.

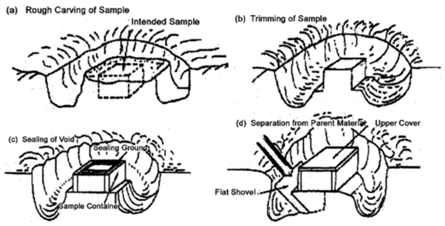


Figure 2 Procedure for Rectangular Block Sampling

1.4 Physical and Chemical Properties of Peat

Index properties (physical and chemical) of peat such as natural moisture content (ω, %), specific gravity (G_s), acidity (pH), initial void ratio (e_o), bulk unit weight (γ_b, kN/m^3), dry unit weight (γ_d, kN/m^3) were determined to establish the basic characteristics of the peat soils.

Variability of peat is extreme both horizontally and vertically. The variability results in a wide range of physical properties such as texture, color, water content, density, and specific gravity. Fibrous peat generally has very high natural water content due to its natural water-holding capacity. Siti Muslikah (2011) has indicated that the average water content of fibrous peat from Ogan Komering Ilir regency, South Sumatra is about 563.88 %. High water content results in high buoyancy and high pore volume leading to low bulk density and low bearing capacity. The water content of peat researched in West Malaysia ranges from 200 to 700 % [2].

Specific gravity of peat depends greatly on its composition and percentage on the inorganic content. The specific gravity of peat ranges between 1.3 and 1.8 with an average of 1.5 [14]. The lower the specific gravity indicates a higher degree of decomposition.

Generally, peat soils are very acidic with low pH values, often lies between 4 and 7 [15]. pH values of 4.82 have been described for fibrous peat [13]. Peat in Peninsular Malaysia is known to have very low pH values ranging from 3.0 to 4.5, the acidity tends to decrease with depth, and the decrease may be large near the bottom layer depending on the type of the underlying soil [16].

Natural void ratio of peat is generally higher than that of inorganic soils indicating their higher capacity for compression. Natural void ratio of 5-15 is common and a value as high as 25 have been reported for fibrous peat by Hanharan (1954).

Unit weight of peat is typically lower compared to inorganic soils. Sharp reduction of unit weight was identified with increasing of water content. Previous researches suggested that for peat water content about 500 %, the unit weight ranges from 10 to 13 kN/m^3. Based on his research, Berry (1983) pointed out that the average unit weight of fibrous peat is about 10.5 kN/m^3. A range of 8.3-11.5 kN/m^3 is common for unit weight of fibrous peat in West Malaysia [2].

1.5 Classification of Peat

The classification of peat soil is based on the decomposition of fiber, the vegetation forming the organic content, organic content, and fiber content. The physical, chemical, and geotechnical characteristic commonly used for classification of inorganic soil may not be applicable to the characterization of peat. Alternatively, properties which are not pertinent to inorganic soil may be important for classification of peat.

The degree of peat decomposition or humification is usually assessed by means of the [5]. The degree of decomposition is grouped into H_1 to H_{10}: the higher the number, the higher the degree of decomposition. The test was conducted by taking a handful of peat and when pressed in the hand, gives off marked muddy water. The peat soil in Kampung Bahru Pontian, West Johore is classified as fibrous peat with low to medium degree of decomposition (H_4 in von Post scale) and of very high organic and fiber content [12].

The peat is further classified based on fiber content [19] because the presence of fiber alters the consolidation process of fibrous peat from that of organic soil or amorphous peat. Amorphous peat is the peat soil with fiber content less than 20 %. It contains mostly particles of colloidal size (less than 2 microns), and the pore water is absorbed around the particle surface. The behavior of amorphous granular peat is similar to clay soil. Fibrous peat is the one having fiber content more than 20 % and possess two types of pore i.e.: macro-pores (pores between the fibers) micro-pores (pores inside the fiber itself).

The classification based on the vegetation forming the organic material is not usually adopted in engineering practice even though researches have indicated that the fiber content or the type of plant forming the peat soil, and degree of decomposition significantly affects the behavior of fibrous peat.

Based on the fiber content [10], peat is classified as fibric peat (> 67 %), hemic peat (33-67 %), and sapric peat (< 33 %). According to [10] (ash content), peat also classified as low ash (< 5 %), medium ash (5-15 %), and high ash (> 15 %). In relation to [10], the peat is classified based on acidity (pH) such as highly acidic(< 4,5), moderately acidic (4,5 - 5,5), slightly acidic (> 5,5-< 7), and basic (≥7).

1.6 Fabric by SEM

Dhowian and Edil showed that fiber arrangement appears to be a major compositional factor in determining the way in which peat soils behave [20]. However, the difference in the fiber content plays an equal important role in the behavior of fibrous peat. The differences in fiber content can be observed in the micrographs through the Scanning Electron Micrograph (SEM).

SEM is an instrument that is routinely used for the production of strongly enlarged images of a specimen. The maximum achievable magnification of the SEM is 500.000 x which uses a combination of X-Ray and micro analysis. The higher the fiber content, the more the peat will differ from an organic soil in its behavior.

1.7 Engineering Properties of Peat

[21] stated that peat soil is known for its low shear strength and high compressibility. These characteristics put the peat soil in a problematic category. The low strength often causes stability problem and consequently the applied load is limited or the load has to be placed in stages. Large deformation may occur during and after construction period both vertically and horizontally, and the deformation may continue for a long time due to creep.

1.7.1 Shear Strength

The shear strength of peat soil is very low; however, the strength could increase significantly upon consolidation. [8] explained the rate of strength increase is almost one-fold compared to soft clay with a rate of strength increase of 0.3.

Direct shear and Triaxial (UU) equipment have been used to determine the shear strength of peat soil. Shear box is the most common test for determining the drained shear strength of fibrous peat and Triaxial test under consolidated-undrained condition is common for laboratory evaluation of undrained shear strength of peat [8].

Landva designated the range of undrained friction angle of 27°-32° under a normal pressure of 3 to 50 kPa [11]. Dhowian and Edil showed that the effective internal friction ϕ' of peat is generally higher than inorganic soil i.e: 50° for amorphous granular peat and in the range of 53°-57° for fibrous peat) [20]. The range of undrained friction angle of peat in West Malaysia is 3°-25° [2].

1.7.2 Permeability

Permeability is one of the most important properties of peat because it controls the rate of consolidation and increase in the shear strength of the soil [22]. The permeability of peat depends on the void ratio, mineral content, degree of decomposition of the peat, chemistry, and the presence of gas.

Previous studies on physical and hydraulic properties of fibrous peat indicated that the peat is averagely porous, and this certifies the fact that fibrous peat has a medium degree of permeability. In its natural state, peat can have a hydraulic conductivity as high as sand, i.e., 10^{-5} to 10^{-4} m/s [23]. Therefore, constant head permeability tests have been used to determine the vertical and horizontal coefficient of permeability of fibrous peat.

Hobbs pointed out the significant decrease in coefficient of permeability with the decrease in void ratio [22]. The wide range of initial coefficient of permeability values was attributed mainly to the wide rnge of initial void ratio of natural peat deposits. The change in permeability as a result of compression is drastic for fibrous peat [20].

Research on Portage fibrous peat shows the soil initially has a relatively high permeability comparable to fine sand or silty sand; however, as compression proceeds and void ratio decreases rapidly, permeability is greatly reduced to a value comparable to that of clay i.e. about 10^{-8} to 10^{-9} m/s [24, 20, 3]. The findings showed that the rate of decrease of hydraulic conductivity with decreasing void ratio is usually higher than that of clays.

1.7.3 Compressibility

The compression behavior of fibrous peat is different from that of clay soil. The compressibility generally occurs in several stages i.e. primary, secondary, and sometimes tertiary consolidation, thus the curve (strain vs log time) consists of four components of strain i.e: (1) instantaneous strain (ε_i), (2) primary strain (ε_p), (3) secondary strain (ε_s), and (4) tertiary strain (ε_t) (Fig. 3).

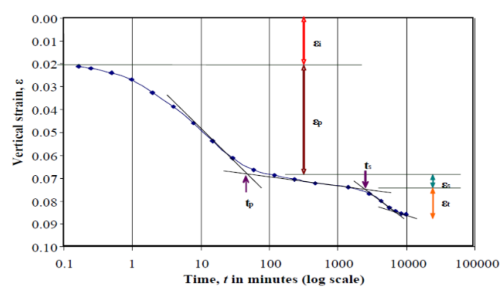


Figure 3 Consolidation behavior of peat

Fiber content is one of the dominant factors controlling the compressibility characteristics of peat. Others include natural water content, void ratio and initial permeability. Problems are raised when secondary compression is found as the more significant part of compression because the time rate is much slower than the primary consolidation. Subsequently the formulae used to estimate the amount of compression is different from that of clay soil.

The followings are important compressibility characteristics of peat: (1) initial void ratio, e_o, (2) pre consolidation pressure, σ'_p, (3) coefficient of compressibility, a_v, (4) end of primary consolidation, t_p, (5) coefficient of rate of consolidation, C_v , (6) coefficient of rebound, C_{vs}, (7) compression and recompression index (C_c and C_r), (8) swelling index (C_s), and (9) secondary compression index (C_α).

Peat soils have a unit weight close to that of water; thus, the in-situ effective stress (σ'_o) is very small and sometimes cannot be detected from the results of consolidation test. It is also very difficult to obtain t_p

from consolidation curve because the preliminary consolidation occurs rapidly. Natural void ratio e_o is very large. The e-log p curves showed a steep slope indicating a high value of a_v and C_c. Published data on c_c ranges from 2-15. [25] pointed out a pronounced decrease in C_v with load during consolidation due to large reduction in permeability. Ratio of C_α/C_c has been used widely to study the behavior of peat. [26] reported a range between 0.05 and 0.07 for C_α/C_c.

2.0 EXPERIMENTAL

Based on the properties of the peat, the objectives of this research are to identify the type of peat and to estimate the engineering properties of peat from Ogan Ilir Regency, South Sumatera, Indonesia. For this research, a laboratory test was conducted on undisturbed samples using the block sampling method.

Index properties (physical and chemical) such as natural moisture content, specific gravity, initial void ratio, unit weight, and acidity were determined to establish the basic characteristics of the peat. The peat was classified based on von Post, fiber content, organic content, and ash content. In order to advance a visual appreciation of the peat their microstructure was examined under SEM. Engineering properties evaluated in this research include strength, compressibility, and permeability.

2.1 Location and Sampling of Peat

Block sampling method was used in this study to obtain the samples of the peat from three locations in Ogan Ilir Regency, South Sumatera, Indonesia. The location are Bumi Inderalaya Permai (BIP), Palemraya, and Semambu. Figure 4 show the location of the sample and the block sampling.

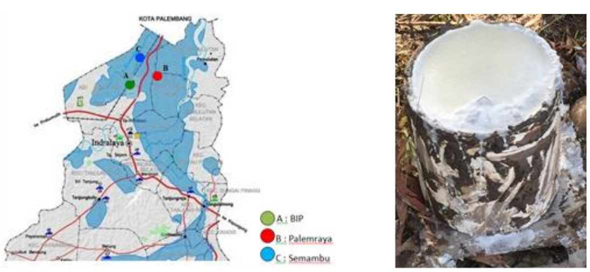


Figure 4 Location of the sample and the block sampling

Block sampling method [10] was selected because it is the best method for obtaining the most representative sample of peat at shallow depth. The soil was excavated to a depth of 1 m and then a tube was pushed slowly into the soil. The surroundings of the sampler was excavated so that samples could be then cut at the base and a thin wooden plate was inserted at the bottom of the sample to cover the bottom of the sample before taking it to the surface. The quality of samples was maintained by ensuring the sharpness of the edge of the tube and knife used to cut the sample.

2.2 Index Properties, Classification, and SEM of Peat

Preliminary laboratory test was conducted to identify the peat and to compare the results to published data. The tests included the determination index properties (physical and chemical) of the soil and soil classification. The SEM was used to observe the fiber orientation of peat.

The natural moisture content (ω) was done following [10] while the determination of the specific gravity (Gs) of peat soil was made following [10]. For unit weight (γ, kN/m^3), the value is calculated based on the natural moisture content, specific gravity, and initial void ratio. In addition, the acidity of the peat was determined by pH meter following [10].

The tests for classification of peat soil are Von Post degree of humification, Mac Farlane (Fiber Content), fiber content [10], ash content [10], and pH [10]. The SEM was used to observe the fiber orientation in of the peat.

2.3 Engineering Properties of Peat

Shear strength, permeability, and compressibility test were done to determine the engineering properties of peat. The constant head permeability test was done on undisturbed sample obtained vertically and horizontally. The tests are done following standard procedures of [10].

Direct Shear and Triaxial equipment have been used to determine the shear strength of peat. Direct shear test following standard procedure [10].

Determination of normal stresses used for the test is based on the estimation of overburden pressure on the soil at depth of 0.5 and 1 m. The analysis of direct shear test was used program of Humboldt Material of Testing Software. Triaxial test under unconsolidated undrained (UU) condition was used for evaluation of undrained shear strength of peat. The test follows the standard procedure outlined in [10].

The standard consolidation test on Oedometer test was conducted as preliminary tests to estimate the consolidation behavior of the peat samples. The tests are carried out based on the standard procedure outlined in [10]. The test is conducted with load increment ratio (LIR) of one, and applied loads were 25 kPa, 50 kPa, 100 kPa, and 200 kPa. Each load was maintained for two weeks or 20,000 minutes for loading stages during the first tests, but was modified to one week or 10,000 minutes upon determination of the end of primary consolidation (t_p) and secondary compression (t_s) of the soil. The standard consolidation test was conducted for two locations (Bumi Inderalaya Permai and Palemraya).

3.0 RESULTS AND DISCUSSION

3.1 Index Properties, Classification, and SEM of Peat

The preliminary identification of the peat was made based on the index properties and the classification tests conducted. Index properties consist of the determination of natural moisture content, specific gravity, acidity, the initial void ratio, and bulk unit weight. The results of the index properties are presented in Table 1. The peat in this study was also classified based on the degree of humification (von Post scale), the fiber content, ash content, and acidity (pH). The summary of the classification test results is shown in Table 2.

Table 1 and 2 show that based on its index properties, and classification, peat is a typical fibrous peat obtained in Ogan Ilir regency (Bumi Inderalaya Permai, Palemraya, Semambu), South Sumatra, Indonesia. Peat was categorized as shallow peat based on the observation made in the location. Groundwater table exists at depth less than 1 m at the time of sampling. Visual identification showed that the peat is dark brown muddy water, very soft, and contains a large amount of fiber.

The results average natural moisture content obtained from laboratory tests are 409,09 % (Bumi Inderalaya Permai), 423,70 % (Palemraya), and 493,01% (Semambu). This value is within the range obtained by previous researchers for peat soil in West Malaysia (Table 1). The average natural moisture content achieved from this study is lower than predicted by [13].

The average specific gravity obtained using kerosene on pycnometer test is also within the range for fibrous peat (Table 1). The initial void ratio includes the volume of gas generated during decomposition process. The average void ratio for the fibrous peat obtained in Ogan Ilir regency is 6.91 and this is within the range given by [2].

Table 1 Index properties of peat

	Parameters	Published Data (ranges)	Results (Ogan Ilir Regency)		
			Bumi Inderalaya Permai	Palemraya	Semambu
Index Properties	Natural Moisture Content, ω (%)	200 – 700	409,09	423,70	493,01
	Specific Gravity (Gs)	1.30 – 1.90	1,40	1,80	1,75
	Acidity (pH)	3.0 – 4.5	4,12	3,94	3,98
	Initial void ratio (e_o)	3 – 15	6,48	6,56	7,68
	Bulk unit weight, γ_b (kN/m^3)	8.30 – 11.50	9,57	11,08	11,94

Table 2 Classification of peat

	Parameters	Published Data (ranges)	Results (Ogan Ilir Regency)		
			Bumi Inderalaya Permai	Palemraya	Semambu
Classification	Von Post (1992)	$H_1 – H_7$	H_4	H_5	H_5
	Mac Farlane (1969) (Fiber Content)	> 20 %	*fibrous peat*	*fibrous peat*	*fibrous peat*
	ASTM D: 4427-13 (Fiber Content)	< 33 %	*sapric*	*Sapric*	*sapric*
	ASTM D: 4427-13 (Ash Content)	> 15%	*high ash peat*	*high ash peat*	*high ash peat*
	ASTM D: 4427-13 (pH)	< 4,5	*highly acidic*	*highly acidic*	*highly acidic*

Fiber orientation is identified as a dominant factor is the structure of fibrous peat. Most of the features of anisotropy of the fibrous peat are visible to the naked eye, a more detailed analysis of the microstructure of the fiber and the fiber content can be examined under a Scanning Electron Microscope (SEM).

The examination is important because previous researcher have shown that the fiber content appears to be a major compositional factor in determining the way in which peaty soils behave [20]. Figure 5 show the typical fiber orientation obtained by SEM for the fibrous peat obtained from Ogan Ilir regency, South Sumatra, Indonesia.

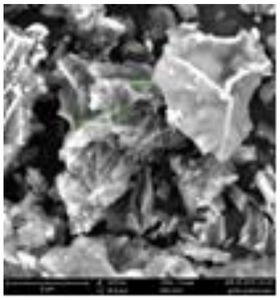


Figure 5 SEM of Peat

3.2 Engineering Properties of Peat

The laboratory evaluation of shear strength was made by Direct Shear and triaxial UU tests. Table 3 shows the average value of the parameter from Direct Shear and Triaxiall UU tests.

The results from direct shear test showed an average effective cohesion (c') of 7.19 kPa (Bumi Inderalya Permai), 9.51 kPa (Palemraya), and 6.17 kPa (Semambu). Beside of that, based on Triaxial UU test, the value of the effective cohesion (c') of 5.15 kPa (Bumi Inderalya Permai), 6.25 kPa (Palemraya), and 3.35 kPa (Semambu). The cohesion value is in the range compared to the published data on peat in West Malaysia [2]. The result of Direct Shear test is shown in Figure 6.

The constant head permeability test was done on sample obtained vertically and horizontally. Table 4 shows the results of the average value of the parameter from permeability test. In general, the results showed in the range permeability compared to published data. The initial permeability in the vertical direction is $6.03.10^{-4}$ m/s (Bumi Inderalya Permai), $5.30.10^{-4}$ m/s (Palemraya), and $6.24.10^{-4}$ m/s (Semambu). For the the horizontal direction are $7.52.10^{-4}$m/s (Bumi Inderalya Permai), $9.93.10^{-4}$m/s (Palemraya), and $7.14.10^{-4}$m/s (Semambu).

The results show that data for fibrous peat in which k_h is higher than k_v. The soil can be classified as medium degree of permeability or the soil has low permeability. The relationship between the initial coefficient of permeability of the soil at standard temperature (k_v 20°C). It is initial void ratio (e_o) is plotted with typical range of data obtained by previous research in Figure 7.

The summary of the consolidation parameters obtained from Oedometer test results including the end of primary consolidation (t_p), end of secondary compression (t_s), rate of consolidation (c_v), and coefficient of secondary compression (c_α) as a function of consolidation pressure is presented in Table 5. Figure 8 shows the time settlement curve from Oedometer test.

Table 3 Average Value of Parameter from Direct Shear and Triaxiall UU Test

Test	Parameters	Published Data (ranges)	Results (Ogan Ilir Regency)		
			Bumi Inderalya Permai	Palemraya	Semambu
Direct Shear	Friction, ϕ' (°)	3-25	19.70	18.60	21.50
	Cohesion, c' (kPa)	6-17	7.19	9.51	6.17
	Shear Strength, τ' (kPa)	3-15	8.07	10.32	7.21
Triaxial UU	Friction, ϕ' (°)	3-25	6.00	7.5	3.75
	Cohesion, c' (kPa)	6-17	5.15	6.25	3.35
	Shear Strength, τ' (kPa)	3-15	5.44	6.72	3.55

Table 4 Average Value of Parameter from Permeability Test

Permeability Test	Parameters	Published Data (ranges)	Results (Ogan Ilir Regency)		
			Bumi Inderalya Permai	Palemraya	Semambu
	Horizontal, k_h (m/sec) 20°C	10^{-5}-10^{-4}	$7.52.10^{-4}$	$9.93.10^{-4}$	$7.14.10^{-4}$
	Vertical, k_v (m/sec) 20°C		$6.03 .10^{-4}$	$5.30.10^{-4}$	$6.24.10^{-4}$

Table 5 The summary of data obtained from Oedometer test

Oedometer Test		Results (Ogan Ilir Regency) Consolidation pressure (p', kPa)									
		Bumi Inderalya Permai					Palemraya				
		25	50	100	200	400	25	50	100	200	400
	End of Primary Consolidation, t_p (minutes)	35.50	30.15	26.26	24.19	21.85	40.78	37.60	32.10	29.50	27.45

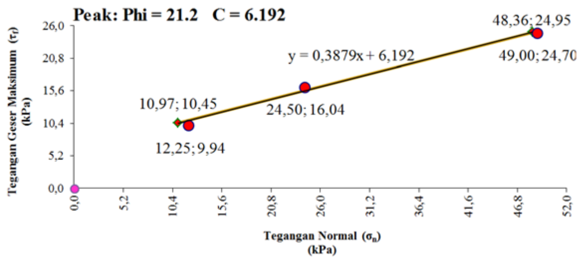


Figure 6 The results of direct shear test from program of humboldt material of testing software

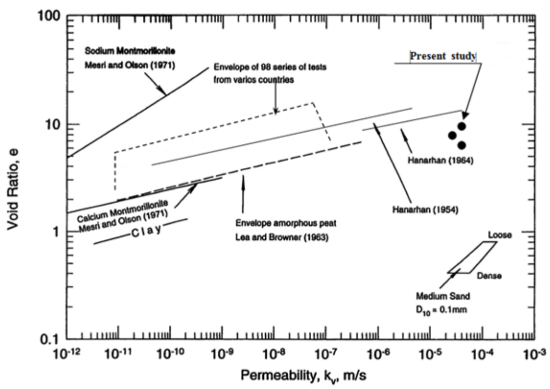


Figure 7 Effect of initial void ratio on the initial permeability of soil [22]

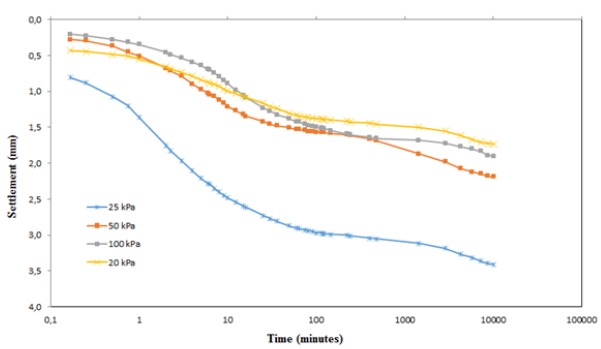


Figure 8 Time settlement curve from oedometer test

	End of Secondary Compression, t_s (minutes)	3250	2910	2540	2355	2145	3587	3251	3010	2715	2420
	Rate of Consolidation, C_v (m^2/year)	2.71	2.14	1.19	0.94	0.85	3.69	3.11	2.15	1.35	1.02
	Coefficient of Secondary Compression, C_α	0.16	0.12	0.13	0.12	0.13	0.14	0.17	0.16	0.15	0.16
	Compression Index, C_c			4.36					3.85		

Based on the results (Bumi Inderalaya Permai) from consolidation test showed that the primary consolidation (t_p) occurs about 28 minutes. The compression index (C_c) is about 4.32. Published data on C_c ranges from 2-15. The coefficient of secondary consolidation C_α is established to be 0.13. This results in C_α/C_c of 0.03 which is in the lower range (0.05 and 0.07) of published data reported by [26]. The coefficient of C_v from Bumi Inderalaya Permai ranged from 2.71 from 0.95 for pressure range of 25 to 200 kPa.

4.0 CONCLUSION

The conclusions of this study are shown in the followings:

i. Peat soils are classified based on degree of decomposition, organic content, fiber content, and water content or void ratio. The peat soil in Ogan Ilir regency is classified as fibrous peat with low to medium degree of decomposition (H_4–H_5 in von Post scale) and of very high organic and fiber content. The natural moisture content of the peat is 409.09 % (Bumi Inderalaya Permai), 423.70 % (Palemraya), and 493.01 % (Semambu).

ii. The results of direct shear test showed the effective cohesion (c') of 7.19 kPa (Bumi Inderalya Permai), 9.51 kPa (Palemraya), and 6.17 kPa (Semambu). And based on Triaxial UU, the value of the effective cohesion (c') of 5.15 kPa (Bumi Inderalya Permai), 6.25 kPa (Palemraya), and 3.35 kPa (Semambu).

iii. The initial permeability in the vertical direction is $6.03 .10^{-4}$ m/s (Bumi Inderalya Permai), $5.30.10^{-4}$ m/s (Palemraya), and $6.24.10^{-4}$ m/s (Semambu). For the the horizontal direction are $7.52.10^{-4}$m/s (Bumi Inderalya Permai), $9.93.10^{-4}$m/s (Palemraya), and $7.14.10^{-4}$m/s (Semambu). The results show that data for fibrous peat in which k_h is higher than k_v.

iv. The coefficient of rate of consolidation (C_v) from Bumi Indah Permai ranged from 2.71 m^2/year from 0.95 m^2/year for pressure range of 25 to 200 kPa which is comparable to published data on fibrous peat.

Acknowledgement

The study is part of fundamental research SATEKS UNSRI entitled "Studi Mengenai Karakteristik Tanah Gambut di Daerah Inderalaya dengan Pengujian Direct Shear dan Oedometer Test". The authors thanks to Dita Marsha Afriani, Aisyah Septriana, Ridho Dwi Santosa, and Septiani Muliawati for providing the data needed for the analysis.

References

[1] Nyoman Sumawijaya, 2006. Hydrology and Peat-Land Development in Indonesia Tropics. *Research and Development Center for Geotechnology, Indonesian Institute of Sciences, Bandung, Indonesia.* 15(3): 279-284.

[2] Huat, Bujang, B. K. 2004. *Organic and Peat Soil Engineering*. Universiti Putra Malaysia Press.

[3] Lea and Brawer. 1963. Highway Design and Construction Over Peat Deposits in the Lower British Colombia. *Highway Research Record.* (7): 1-32.

[4] Berry, P. L. 1983. Application of Consolidation Theory for Peat to the Design of a Reclamation Scheme by Preloading. Q. *J. Eng. Geol.,* London. 16(9): 103-112.

[5] Von Post, L. 1992. Sveriges Geologiska Undersoknings Torvinventering Och Nagre av Dess Hittills Vunna Resultat. *Sv. Mosskulturfor. Tidskr.* 1:1-27.

[6] Hansbo, S. 1991. Full-scale Investigations of the Effect of Vertical Drains on the Consolidation of a Peat Deposit Overlying Clay. *De Mello Volume,* Published by Editoria Edgard Bldcher LTDA, Caixa Postal 5450, 01051 SAo Paolo-sp Brasil.

[7] Nurly Gofar. 2000. Undrained Behavior of Saturated Soft Clay in South Sumatra. *Proceedings of Annual Seminar of Science and Technology'99 HEDS JICA*, Batam, Indonesia, 22 – 25 February.

[8] Noto, Shigeyuki. 1991. *Peat Engineering Handbook*. Civil Engineering Research.

[9] Lefebre, G. K., Langlois, P., Lupien, C., Lavallde , J. G. 1984. Laboratory Testing and in-situ Behavior of Peat as Embankment Foundation. *Can. Geotech. I.,* Ottawa, Canada. 21(2): 101-108.

[10] American Society for Testing and Materials. *Annual Book of ASTM Standard*. D 7015-04, 4427-13, 2974-14, 854-14, 2434-68, 3080M-11, 2976-71, and 2435-96.

[11] Landva et al. 1983. Compressibility and Shear Characteristics of Radforth Peats. *Testing of Peat and Organic Soils, ASTV STP* 820: 157-191.

[12] Yulindasari. 2006. *Compressibility Characteristics of Fibrous Peat Soil*. Master Thesis, UTM.

[13] Siti Muslikah. 2011. *Studi Degradasi Tanah Gambut oleh Mikroorganisme untuk Proses Konsolidasi Tanah.* Master Thesis. Univeritas Indonesia.

[14] Davis, J. H. 1997. The Peat Deposits of Florida their Occurrence, Development and Uses. *Florida Geological Survey*. Geological Bulletin, 3.

[15] Lea, F. M. 1956. *In the Chemistry of Cement and Concrete.* ed. Lea and Desch: 637. London : Edwar Arnold Ltd.

[16] Muttalib. 1991. Characterization, Distribution, and Utilization of Peat in Malaysia, In *Proceedings of the International Symposium on Tropical Peatland,* ed. Aminuddid, Kuching, Sarawak: 7-16.

[17] Hanharan, E. T. 1954. An Investigation of Some Physical Properties of Peat. *Geotechnique,* London, England. 4(2): 108-123.

[18] Berry, P.L. 1983. Application of Consolidation Theory for Peat to the Design of a Reclamation Scheme by Preloading. Q. *J. Eng. Geol.,* London. 16(9): 103-112.

[19] Mac Farlane. 1969. A Review of The Engineering Characteristics of Peat. *Journal Of Soil Mechanics and Foundations Division.* SM-1: 21-35.

[20] Dhowian and Edil. 1980. Consolidation Behavior of Peats. *Geotechnical Testing Journal*. 3(3): 105-114.

[21] Nurly Gofar and Yulindasari Sutejo. 2005. *Engineering Properties of Fibrous Peat*, Proc. Seminar Penyelidikan Kej. Awam (SEPKA 2005), Johor Bahru: 119-129.

[22] Hobbs. 1986. Mire Morphology and the Properties and Behaviour of Some British and Foreign Peats. Q. *I Eng. Geol.,* London. 19(1): 7-80.

[23] Colleselli et. al. 2000. Laboratory Testing of Italian Peaty Soils, *Geotechnics of High Water Contents Materials*, ASTM STP1374, ed. Edil and Fox, 226-242.

[24] Hillis and Brawner. 1961. The Compressibility of Peat with References to Major Highway Construction in British Columbia. *Proceeding*. Seventh Muskeg Res. Conf., NRC, ACSSM Tech. Memo. 71:204-227.

[25] Ajlouni. 2000. *Geotechnical Properties of Peat and Related Engineering Problems.* Thesis. University of Illinois at Urbana-Champaign.

[26] Mesri. 1994. Cc/Ca Concept Applied to Compression of Peat. Discussion, *J. Of Geotech. Engrg., ASCE.* 118(8): 764.