Fiber Effects on Compressibility of Peat

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Abstract. Fibers found in the soil, especially in peaty soil play an important role in the determination of soil compressibility. Peat soils are the results from the decomposition of organic matter and the type of peat can be classified based on the fibrous material in the soil. In the engineering field, peat soil was mostly known as soils that has a serious settlement with high compressibility index. From the previous research, fibers in the soil were influenced in compressibility in terms of size, shape, fibric, soil arrangement and etc. Hence, this study attempts the determination of fibers effects on the compressibility of peat using a 1-D oedometer consolidation test. The reconstituted peat samples of different particle sizes were used to determine the consolidation parameters and the results obtained from reconstituted samples were also compared with the undisturbed sample. 1-D oedometer consolidation tests were performed on the samples by using the load increment method. The results shows, the higher particle size (R3.35), give higher moisture content ($w = 401.20\%$) and higher initial void ratio ($e_0 = 5.74$). In settlement prediction, the higher the fiber content will results the higher the compression index, therefore, it will cause high of settlement.

Keywords: Soft Soil, ground modification, settlement.

1. Introduction
A soil can be classified as peat when the organic content of the soil exceed 75% as stated in ASTM D4427 [2]. Peat is mainly known as highly organic soils disintegrated primarily from plants remains, and undergo decomposition for a long time period. This type of soil has pale to dark brown or black in color, depends on its decomposition and time it was deposited. It can be classified into 3 types, which are, fibric (least decomposed), hemic (moderately decomposed) and sapric (highly decomposed) [9]. The classification of peat can be based on Von Post Classification system and the fiber content of the peat. Peat can be found all over the world, including Malaysia.

Malaysia Wetlands International [21], has reported that peat have covered 2,457,730 hectares from the total land surface in Malaysia. The largest area covered by peat was contributed by Sarawak (1,697,918 ha; 69.08% from the total), followed by Peninsular Malaysia (642,918 ha; 26.16%) and Sabah (116,965 ha; 4.76%). In Peninsular Malaysia, peat is located in most states and can be found in Johor, Selangor, Pahang, Perak, Terengganu, and Kelantan. Leete [11] has stated about 228,960 ha of peat were located in Johor and the selected location of this study were in West Johor.
In engineering purpose, peat soils are unsuitable for supporting or resist loads in its natural states [6]. Peat soils unable to perform well for most engineering structures and hence, pose serious settlement problems. However, development of peaty soil is inevitable since Malaysia has a deficiency on land surface to cater the population growth and rapid development moving towards a developed country. Whitlow [22]; Razali, Bakar and Zainorabidin [18], have highlighted that peaty type of soil has high compressibility with initial void ratio in the range of 5 – 15, low bearing capacity (5 – 20 kPa), high moisture content, which may up to 1000% depends on it compositions, high organic content (more than 75%) and high fiber content which leads to serious settlement issues. The soil experiences an excessive settlement for a short period and continues to settle for a long period of time. Based on a few research programs, compressibility of peat greatly affected from the decomposition of peat. The lower the decomposition, the higher the compressibility as it consists of fibrous organic matter like leaves and plant stems that have high porosity, which leads to high initial void ratio, high moisture and fiber content which was reported by Santaga, Bobet, Johnston and Hwang [19]. Besides those factors, the compressibility of peat also influenced by the size, shape, fibric and the arrangement of the constituent fibers, initial permeability and inter-particle of chemical bonding in the soil [13, 15, 23].

![Figure 1. Physical peat model [23.]](image1)

![Figure 2. Schematic diagram of peat arrangement [23.]](image2)

By the determination of fiber content in the peat, the type of peat could be known. Based on the ASTM D1997 [2], the determination of peat types is through the percentage of fiber, retained on 150µm sieve apertures over the total weight. Peat soil with a fiber content of more than 67% was classified as fibric peat, where less than 33% was sapric peat and 33 – 67% was hemic peat. Boelter [3] reported that fiber content gives a high impact on the difference of physical properties of peat soil especially in compressibility. The higher fiber content and low bulk density in decomposed peat contain many large pores which are yielding as much as 80% of their saturated water content for
drainage and water movement. Hence, it increases the settlement of peat by itself. Fibrous peat typically made of the weakly decomposed plant remains which are not destroyed by rubbing, which is making it extremely acidic and has high fiber content [1]. It also has been reported by Kogure et al. [12] that the settlement on peat is higher compared to other soils such as clay and sand because of the inner and the outer void spaces in peat. Edil and Wang [14] added, by increasing the fiber content in the soil, it has influenced in increases the values of moisture content and void ratio.

By the presence of the fiber, it affected the structural arrangement of peat. Kogure et. al. [12] has developed and introduced to the physical model of peat as in figure 1, which peat has divided into two major components comprising organic bodies and organic spaces. The organic bodies consist of organic particles as solids and the inner voids filled with water, whereas, the organic spaces, including the soil particles as solids and the outer voids filled with water. Wong et. al [23] was drew a schematic diagram in figure 2, based from the findings in figure 1. The schematic diagram gives a clear explanation about the peat arrangement which consists of fibers and organic particles. In the organic particles, Hobbs [15,16] stated that, there had three main constituents, derived from plant stems and roots which are coarse fibers with particles sizes greater than 1 mm in diameter, finer fibers with sizes smaller than 1 mm in diameter and amorphous matter (completely decayed). At initial states, peat can hold a considerable amount of water due to the hollow and spongy of the particles and results high of moisture content and initial void ratio. Hence, depending by the fibers, size and particle arrangement, compressibility and the consolidation of soil could be predicted as well as the aim of this paper, to study the effects of peat fibers in compressibility by conducting 1- D oedometer test on the undisturbed sample and reconstituted samples with two different particle sizes.

2. Experimental Program

2.1. Sampling of Peat

The type of peat used in this study was a hemic peat or shall be known as pseudo-fibrous peat, collected from Parit Nipah Darat, Johor. In order to obtain the undisturbed and disturbed samples, the soil was excavated between depths of 0.3 to 1.2m below ground surface. The tube samplers of 100mm in diameter x 200mm in height with having a sharp edge at the lower end were used to collect the undisturbed peat samples. The tubes were immediately waxed after sampling on both ends, and sealed using layers of plastic film. This is to preserve the moisture content of samples while the disturbed sample was randomly collected at the same depth and placed in plastic bags. Then the peat samples were placed in a plastic container, covered with lid and kept in a laboratory at a constant temperature. Sampling of peat have been done quickly to avoid collecting more water due to the ground water level of peat was high, that is at the depth 0.3m from the ground surface. The Von Post classification test was also done at the site on fresh peat. About one-third of the soil was passed the fingers and the color of water released was very muddy dark brown. Hence, the peat sample taken was classified as H5 (moderately decomposed).

2.2. Sample Preparation

Types of samples used in this study were undisturbed sample (as original sample) and reconstituted samples. These samples were used to determine the consolidation parameter by conducting 1- D oedometer consolidation test. However, the disturbed samples were used to determine the index properties of the soil.

The reconstituted samples were prepared by the author in the Research Centre of Soft Soils, Malaysia (RECESS) with a specific procedure. The preparations of the sample were done by several steps: 1) Sieving; 2) Reconstituting; and 3) extrusion. At the sieving step, the disturbed sample was sieved using 0.300mm and 3.35mm sieve apertures with the aid of some water to remove the larger particles of organic matter and produce the slurry sample. The sizes selected were part of research conducted by the authors and the largest and smallest sizes have been chosen for this study. Then, the slurry sample of peat has been collected and placed in the reconstitution mould. For the preloading
stage, the slurry peat of both sizes of peat particles was subjected to pressure of 50 kPa through deadweights as a preloading by using large strain consolidation equipment and maintained until the flow of excess pore water pressure stopped. After the reconstitution process, the reconstituted sample was extruded and trimmed into a consolidation ring with 75 mm in diameter x 20 mm height, for the 1-D oedometer test and the residue of the sample has been collected and tested for index properties as comparison purposes.

2.3. Index Properties of Original Peat and Reconstituted Peat
The properties of the natural peat sample and reconstituted peat of Parit Nipah Darat were as shown in the Table 1. The moisture content, w for peat samples was determined by using oven, drying over 24 hours at 105±5°C, which to remove the moisture in peat [17]. The moisture content for natural states of peat was 640.09%, while for the reconstituted samples for peat particles passing sieve 0.300mm (R0.300) and 3.35mm (R3.35) were 389.48% and 401.20% respectively. The values for the liquid limit (LL) determination were using 80g of 30° fall cone penetration apparatus [2]. As allowed and stated in the standards, the coarse fibers and organic particles in the natural sample were removed to determine the LL values. The specific gravity of natural samples (1.359) was higher than reconstituted samples with 1.281 (R0.300) and 1.334 (R3.35). The determination of specific gravity was conducted using small pycnometer method. The organic content was determined by the loss of ignition method, using muffle furnace (burned at 440±5°C). Fibers content determination was done by separation of fibrous materials from the soil specimen using 150µm sieve. The entire tests were conducted to all specimens to determine the differences between them and the results are as discussed in discussion part.

2.4. 1-D Oedometer Consolidation Tests
All the specimens of the peat samples were tested using a 1-D oedometer consolidation test with the purpose of the evaluation of the effect of fibers in different peat particle sizes and in natural peat in terms of compressibility. The sample specimens were prepared by specific procedure as mentioned in sample preparation and the method used in this testing program was incremental loading method with a stress range of 5 – 320 kPa. For each loading stage, the loading was maintained for 24hrs and the data were recorded as prescribed in ASTM D2435 [2] standards. The specimens were drained from the top and bottom. The tests were conducted in the same laboratory, Research Centre of Soft Soils, Malaysia (RECESS), UTHM.

| Peat Properties | Parit Nipah Darat Peat | Reconstituted Samples Passing 3.35mm (R3.35) | Reconstituted Samples Passing 0.300mm (R0.300) |
|----------------|------------------------|---------------------------------------------|---------------------------------------------|
| Moisture Content, w (%) | 640.09 | 401.20 | 389.48 |
| Liquid Limit, LL (%) | 322 | 325 | 305 |
| Specific Gravity | 1.36 | 1.33 | 1.28 |
| Organic Content (%) | 83.01 | 51.43 | 53.20 |
| Fiber Content (%) | 61.42 | 37.82 | 11.51 |
| Initial Void Ratio, e0 | 8.36 | 5.74 | 5.39 |
| Peat density (kg/m³) | 1075 | 1010 | 1041 |

3. Experimental Results and Analysis
The experimental results obtained that have been highlighted were based on the determination of consolidation parameters of preconsolidation pressures, p<sub>c</sub>, compression index, Cc, swelling index, Cs,
coefficient of consolidation, $c_v$, coefficient of volume compressibility, $m_v$, and compression ratio, $Cr$, which collected from 1-D oedometer consolidation testing. In this study, the data obtained have been analyzed by using the Taylor’s curve fitting method (square root time method) as the method was the most suitable and gives a better curve fitting for the determination of $c_v$ values and have been reported by Wong et. al [24] and Hassan et. al [7].

3.1. Consolidation Parameters of undisturbed and Reconstituted Samples
The $p_c$ value for undisturbed (UD) peat was 13 kPa and for reconstituted samples (R0.300 and R3.35) were 23 kPa and 26 kPa respectively. Based on figure 3, the $C_c$ and $C_s$ values for all the specimens were evaluated from the slopes of the graph. The $C_c$ values were evaluated from the slopes of loading, curves where $C_s$ values were evaluated by the slopes of unloading curves. Table 2 presents the results for $C_c$ were 2.68 (UD), 1.88 (R0.300) and 2.40 (R3.35) while for $C_s$ values were 0.17 (UD), 0.18 (R0.300) and 0.17 (R3.35). The $C_c$ values were decreasing as the sizes of soil particles decreases. The undisturbed samples might have random of soil particles sizes since the peat sample was classified in moderately decomposed. The fibrous materials are contained in the sample has influenced the $C_c$ values. As mentioned before, the fibrous materials have hollow structure and can hold a considerable amount of water. Hence, it will greatly affect in $C_c$ values as shown between samples R3.35 and R0.300. However, for $C_s$ values, the values show slightly different between the samples. The $C_s$ values increase when the size of soil particles decreases. The fibrous materials, in sample R3.35 were unable to absorb the large amount of water, compared to the sample R0.300 which has less fibrous matter.

Compression ratio, $Cr$ was calculated from $C_c/(1+e_0)$, that used to classify the compressibility of a soil [5]. As reported by O’Loughlin and Lehane [5], classification of peat soil were divided by four classes; very slightly compressible ($Cr = 0 – 0.05$), slightly compressible ($Cr = 0.05 – 0.10$), moderately compressible ($Cr = 0.10 – 0.20$) and very compressible ($Cr = > 0.20$). By referring to Table 2, the $Cr$ values for three types of specimens were larger than 0.20 which indicates the peat specimens from Pt. Nipah Darat were very compressible.

![Figure 3](image-url) 

**Figure 3.** Graph of $e$ against log $\sigma$ for undisturbed peat and reconstituted peat samples.
Table 2. Consolidation parameters for peat specimens.

| Parameters               | Undisturbed Peat Sample (UD) | Reconstituted Samples Passing 3.35mm (R3.35) | Reconstituted Samples Passing 0.300mm (R0.300) |
|--------------------------|------------------------------|---------------------------------------------|-----------------------------------------------|
| Initial Void Ratio, $e_o$| 8.36                         | 5.74                                        | 5.39                                          |
| Preconsolidation Pressure, $p_c$, kPa | 13                            | 26                                          | 23                                             |
| Compression Index, $C_c$  | 2.68                         | 2.40                                        | 1.88                                          |
| Swelling Index, $C_s$     | 0.17                         | 0.17                                        | 0.18                                          |
| Compression Ratio, $C_r$  | 0.29                         | 0.36                                        | 0.29                                          |
| Coefficient of consolidation, $c_v$ (m$^2$/yr) | 10.305–0.482                | 17.379–0.696                                | 5.723–0.782                                   |
| Coefficient of Volume Compressibility, $m_v$ (m$^2$/MN) | 16.594–0.887                | 3.512–0.361                                 | 5.589–0.799                                   |

The coefficient of consolidation, $c_v$, decreases with increase of stress as shown in Table 2. For undisturbed sample, the $c_v$ values were in the ranges of 10.305 to 0.482 m$^2$/yr while for R0.300 was 5.723 to 0.782 m$^2$/yr and for R3.35 was 17.379 to 0.696 m$^2$/yr. The $c_v$ values for sample R3.35 were larger than sample R0.300. The sample of R3.35 has contain larger soil particle size than R0.300 sample, which means that the R3.35 sample has high initial void ratio and high in moisture content. Hence, the dissipation of water out from consolidation process which results the $c_v$ value was high compared to R0.300 sample. On the other side, the coefficient of volume compressibility, $m_v$ for all types of specimens were also decreases as the consolidation pressures of oedometer increase. The $m_v$ values were depends on the void ratio and stress pressure and decreases when stress increases. The $m_v$ values for undisturbed sample clearly larger than reconstituted sample, which were decreased from 16.594 to 0.887 where the specimen has a high void ratio compared to the other specimens meanwhile, the $m_v$ values for reconstituted peat of R3.35 were 3.512 to 0.361 and R0.300 were 5.589 to 0.799.

3.2. Fiber Content, Water Content, and Consolidation Parameters ($e_o$, $C_c$, and $C_s$)

Table 3 presented the fiber content and consolidation parameters for peat specimens. The fiber content in UD sample was high with 61.42%, compared to reconstituted peat samples with 11.51% for R0.300 and 37.82% for R3.35. Based on the peat classification, the peat samples collected from Parit Nipah Darat was in a class of hemic with moderately decomposed peat since the fiber content in between 33% to 67%. The fiber content seems to decrease when the sizes of peat particles decrease as shown in reconstituted samples, R3.35 and R0.300 with 37.82% and 11.51%. The amount of fibers in specimens affected the moisture content and initial void ratio [14]. The fiber content of the sample will increase the moisture content and voids as shown in the Table 3. The undisturbed peat has 640.08% of water content and 8.36 of the initial void ratio, whereas for specimens of R0.300 was 389.48% and 5.39 and for R3.35 was 401.20% and 5.74.

As has been mentioned earlier, compressibility of peat has been affected by fibrous particles, mainly come from the fibers and organic particles. Figure 4 shows the illustration of hollow structures of fibers in peat by scanning electron micro-photographs. The photographs show, the peat sample have large pores where makes the sample spongy and can hold a considerable amount of moisture content in their structures which may up to 1000% and resulted the high of an initial void ratio. The higher the amount of fiber contents, the higher the moisture content and the void ratio. Hence, in compressibility, it will increase the compression index where it was one of the important indicators in prediction of soil settlement. These are proven by consolidation parameter of compression index, $C_c$. The $C_c$ value of UD specimens was higher than other specimens with 2.682, followed by R3.35 and R0.300 with 2.400 and 1.882 respectively. The values were decreasing as the size of soil particles and the fiber content
decrease. The fibers that reduced by sieving passing selected sizes of sieve apertures and clearly proved that samples with more fibrous materials have influenced in compression index, initial void ratio and water content. However, in Cs value determination, the values were not too affected by the fibers. The values between the samples were only show slightly different between the samples. The Cs values increase by decreasing the size of soil particles. The fibers in the fibrous specimen were unable to reabsorb the water that has been dissipated out by the consolidation process compared to the sample with less fibrous matter. This was shown that the peat sample with high fibrous material will experience less swelling after preloading phase compared to peat sample which has completely decomposed (high degree of humification) or known as amorphous peat.

| Table 3. Fiber content and consolidation parameters for peat specimens. |
|--------------------------------------------------|
| Peat Type                                         |
|                                                  |
| Undisturbed Peat Sample (UD)                      |
| Reconstituted Samples Passing 3.35mm (R3.35)      |
| Reconstituted Samples Passing 0.300mm (R0.300)    |
|                                                  |
| Fiber content, %                                  |
| 61.42                                            |
| 37.82                                            |
| 11.51                                            |
|                                                  |
| Moisture Content, %                               |
| 640.08                                           |
| 401.20                                           |
| 389.48                                           |
|                                                  |
| Initial Void Ratio, e_o                          |
| 8.36                                             |
| 5.74                                             |
| 5.39                                             |
|                                                  |
| Preconsolidation Pressure, p_c, kPa               |
| 13                                               |
| 26                                               |
| 23                                               |
|                                                  |
| Compression Index, Cc                            |
| 2.68                                             |
| 2.40                                             |
| 1.88                                             |
|                                                  |
| Swelling Index, Cs                               |
| 0.17                                             |
| 0.17                                             |
| 0.18                                             |

Figure 4. (a) and (b) Scanning Electron Microphotograph of peat specimen [13].

4. Conclusion
As a conclusion, fiber content in peat strongly affecting the compressibility of the soil especially peaty type of soil. The higher the fiber content in fibrous peat was increasing the water content, initial void ratio and its compression index. The high fiber content in undisturbed sample cause the high of an initial void ratio, moisture content and hence causing high compression index, Cc which indicates the high of settlement. The fiber content was distinguished by reconstituting samples with different sizes of soil particles passing two selected sieves (R3.35 and R0.300) and this study has proved that the
different peat particle sizes have different values of fiber content. The higher the fiber content contains in the soil, the higher the soil compressibility and hence, the higher the settlement and these results were useful in gaining the information on predicting the settlement of peaty soil.

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