EFFECT OF RECONSTITUTED METHOD ON SHEAR STRENGTH PROPERTIES OF PEAT

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A thesis submitted in partial fulfilment of the requirement for the award of the Degree of Master of Civil Engineering

Faculty of Civil and Environmental Engineering
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“Special dedicated with much love and affection to my beloved parents,
Haji Wahab bin Ngah and Hajjah Munah binti Mohd Nor,
and beloved siblings,
Norhayati, Shaifudin, Noraizam, Azizudin, Nasarudin and Norhashima
Also my booster energy (nieces)
Arissya, Adam, Haziq, Irfan, Auni Camellia and Nafis
In addition, person who’s always support me
Tok, Tokki, Cik Ngoh, Ayah De, Mok Teh Ani, Mok yah, Abang Ri, Kak Ti, Umi,
My ex- supervisor Emeritus Prof Dato’ Dr. Ismail bin Hj. Bakar
Also my current supervisor Dr. Mohd Khaidir bin Abu Talib
and also to all my fellow friends who always helped me and encourage myself to
complete my study in Master of Civil Engineering”

Thank you for always being there for me.
Without your support this would mean nothing.
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*In the name of Allah, Most Gracious, Most Merciful*

Alhamdulillah, all the praise for Allah S.W.T. the most graceful and merciful; who give me the courage and faith for me along the period to accomplish this postgraduate project. Praise is to Allah for, without His will, I would have not able to complete this project.

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ABSTRACT

Peat is an organic soil contains more than 75% organic content. Shear strength of the soil is one of the most important parameters in engineering design, especially during the pre-construction and post-construction periods, since used to evaluate the foundation and slope stability of soil. Peat normally known as a soil that has very low shear strength and to determine and understand the shear strength of the peat is difficult in geotechnical engineering because of a few factors such as the origin of the soil, water content, organic matter and the degree of humification. The aim of this study was to determine the effective undrained shear strength properties of reconstituted peat. All the reconstituted peat samples were of the size that passing opening sieve 0.425mm, 1.000mm, 2.360mm and 3.350mm and were pre-consolidated at pressures of 50 kPa, 80 kPa and 100 kPa. The relationship deviator stress- strain, $\sigma_{d\text{max}}$ and excess pore water pressure, $\Delta u$, shows that in both of reconstituted and undisturbed peat gradually increased when confining pressure, $\sigma'$ and pre-consolidation pressure, $\sigma_c$ increased. As a conclusion, the undrained shear strength properties result obtained shows that the RS3.350 has higher strength than RS0.425, RS1.000 and RS2.360. However, the entire reconstituted peat sample shows the increment value of the shear strength with the increment of peat size and pre-consolidation pressure. For comparison purposes, the undrained shear strength properties result obtained shows that the reconstituted peat has higher strength than undisturbed peat. The factors that contributed to the higher shear strength properties in this study are segregation of peat size, pre-consolidation pressure, initial void ratio and also the physical properties such as initial water content, fiber content and liquid limit.
ABSTRAK

Gambut adalah tanah organik mengandungi lebih daripada 75% kandungan organik. Kekuatan ricih tanah adalah satu parameter yang paling penting dalam rekabentuk kejuruteraan, terutamanya semasa tempoh pra-pembinaan dan selepas pembinaan, digunakan bagi menilai asas dan cerun kestabilan tanah. Gambut biasanya dikenali sebagai tanah yang mempunyai kekuatan ricih yang sangat rendah dan untuk menentukan dan memahami kekuatan ricih tanah gambut adalah sukar dalam bidang kejuruteraan geoteknikal disebabkan beberapa faktor seperti asal-usul tanah, kandungan air, bahan organik dan tahap penguraian gambut. Tujuan kajian ini adalah untuk menentukan ciri-ciri berkesan kekuatan ricih taktersalir penstrukturan semula gambut. Semua sampel penstrukturan semula gambut melepasai saiz bukaan ayak 0.425mm, 1.000mm, 2.360mm dan 3.350mm dan dikenakan tekanan pra-penyatuan 50 kPa, 80 kPa dan 100 kPa. Hubungan tegasan terikan sisih, σdmax dan lebihan tekanan air liang, Δu, menunjukkan bahawa kedua-dua tanah penstrukturan semula gambut dan gambut takterganggu secara beransur-ansur meningkat apabila tekanan terkurung, σ’ dan tekanan pra-penyatuan, σc meningkat. Kesimpulannya, keputusan ciri-ciri kekuatan ricih taktersalir yang diperolehi menunjukkan bahawa RS3.350 mempunyai kekuatan lebih tinggi daripada RS0.425, RS1.000 dan RS2.360. Walau bagaimanapun, sampel bagi keseluruhan penstrukturan semula gambut menunjukkan nilai kenaikan kekuatan ricih dengan peningkatan saiz tanah gambut dan tekanan prapenyatuan. Bagi tujuan perbandingan, keputusan ciri-ciri kekuatan ricih taktersalir yang diperolehi menunjukkan bahawa penstrukturan semula gambut mempunyai kekuatan yang lebih tinggi daripada tanah gambut takterganggu. Faktor-faktor yang menyumbang kepada ciri-ciri kekuatan ricih yang lebih tinggi dalam tesis inin adalah pengasingan saiz gambut, tekanan pra-penyatuan, nisbah lompong asal dan juga ciri-ciri fizikal seperti kandungan air awal, kandungan serat dan had cecair.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE</td>
<td></td>
<td>i</td>
</tr>
<tr>
<td>DECLARATION</td>
<td></td>
<td>ii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td></td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td></td>
<td>iv</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td></td>
<td>v</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td></td>
<td>vi</td>
</tr>
<tr>
<td>TABLE OF CONTENT</td>
<td></td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF TABLE</td>
<td></td>
<td>xii</td>
</tr>
<tr>
<td>LIST OF FIGURE</td>
<td></td>
<td>xiv</td>
</tr>
<tr>
<td>LIST OF SYMBOL AND ABBREVIATION</td>
<td></td>
<td>xviii</td>
</tr>
</tbody>
</table>

## CHAPTER 1 INTRODUCTION

1.1 Background study  
1.2 Problem statements  
1.3 Research objectives  
1.4 Scopes of research  
1.5 Significance of research  
1.6 Structure of thesis  

## CHAPTER 2 LITERATURE REVIEW

2.1 Introduction  
2.2 Peat  
2.3 Classification of peat  
2.4 Particle size distribution  
   2.4.1 Distribution of peat size  
2.5 Physical properties of peat
CHAPTER 3 METHODOLOGY

3.1 Introduction 53
3.2 Peat samples 55
   3.2.1 Disturbed peat samples 55
   3.2.2 Undisturbed peat samples 56
3.3 Particle size distribution (BS1377 Part 1: 1990) 58
3.4 Preparation of reconstituted peat samples 60
CHAPTER 4 RESULTS AND DISCUSSIONS

4.1 Introduction 81
4.2 Von Post classification 81
4.3 Particle size distribution 83
4.4 Physical properties 84
4.4.1 Water content 84
4.4.2 Liquid limit 86
4.4.3 Specific gravity 88
4.4.4 Organic content 90
4.4.5 Fiber content 91
4.5 Summarise of physical properties 93
4.6 Consolidated undrained identification tag of reconstituted peat 96
4.7 Relationship of stress- strain and excess pore 96
4.7.1 Stress-strain relationships for undisturbed and reconstituted Parit Nipah peat

4.7.1.1 Stress-strain relationships at pre-consolidation 50kPa on deviator stress, \( \sigma_{d_{max}} \) (kPa)

4.7.1.2 Stress-strain relationships at pre-consolidation 80kPa on deviator stress, \( \sigma_{d_{max}} \) (kPa)

4.7.1.3 Stress-strain relationships at pre-consolidation 100kPa on deviator stress, \( \sigma_{d_{max}} \) (kPa)

4.7.2 Excess pore water pressure-strain relationships for undisturbed and reconstituted Parit Nipah peat

4.7.2.1 Excess pore water pressure-strain relationships of undisturbed and reconstituted peat at pre-consolidation 50kPa

4.7.2.2 Excess pore water pressure-strain relationships of undisturbed and reconstituted peat at pre-consolidation 80kPa

4.7.2.3 Excess pore water pressure-strain relationships of undisturbed and reconstituted peat at pre-consolidation 100kPa

4.8 Shear strength properties

4.9 Effect of reconstituted peat samples on shear strength properties

4.10 Summary
CHAPTER 5 CONCLUSIONS

5.1 Introduction 125
5.2 Conclusions 125
5.3 Recommendation 130

REFERENCES 131

APPENDIX
## LIST OF TABLES

1.1 Proportionate distribution of peat in Malaysia  
(Wetlands International Malaysia, 2010; and CREAM, 2015)  

1.2 Thesis outline  

2.1 Distribution area of peat in Malaysia (CREAM, 2015)  

2.2 Summary description and determination of peat soil  

2.3 General purpose definition of peat  

2.4 Peat classification according to degree of humification  
(Von, 1992 and Adon *et. al*, 2012)  

2.5 Organic soil classification based on the organic content  
Jarret (1995)  

2.6 Classification based on the fiber content of peat (Jarret, 1995)  

2.7 Definition and significance of the test  

2.8 Classification of soil chart (ASTM D2487-06)  

2.9 The physical properties of peat soil in Malaysia  

2.10 Soil specimen description  

2.11 Factors control the shear strength (Poulos, 1989)  

2.12 Undrained shear strength of fine soils  
(BS EN ISO 14688-2:2004)  

2.13 Undrained shear strength of peat  

2.14 Shear strength parameter and pre-consolidation pressure of the reconstituted soil (Rabbee *et al.*, 2012)  

2.15 Shear strength under pre-consolidation pressure of the reconstituted peat (Anggraini, 2006)  

2.16 Method to strengthen and toughen peat soil  

3.1 Total reconstituted peat samples  

3.2 Experimental method based on standard  

4.1 Result of particle size distribution test for undisturbed and
reconstituted peat

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.2</td>
<td>Water content for undisturbed and reconstituted peat</td>
<td>85</td>
</tr>
<tr>
<td>4.3</td>
<td>Liquid limit for undisturbed and reconstituted peat</td>
<td>87</td>
</tr>
<tr>
<td>4.4</td>
<td>Specific gravity for undisturbed and reconstituted peat</td>
<td>89</td>
</tr>
<tr>
<td>4.5</td>
<td>Organic content for undisturbed and reconstituted peat</td>
<td>91</td>
</tr>
<tr>
<td>4.6</td>
<td>Classification of reconstituted soil from organic content range</td>
<td>91</td>
</tr>
<tr>
<td>4.7</td>
<td>Fiber content for undisturbed and reconstituted peat</td>
<td>92</td>
</tr>
<tr>
<td>4.8</td>
<td>Classification of reconstituted soil from fiber content range</td>
<td>93</td>
</tr>
<tr>
<td>4.9</td>
<td>Summary of physical properties on Parit Nipah peat soil</td>
<td>95</td>
</tr>
<tr>
<td>4.10</td>
<td>Summary of deviator stress at pre-consolidation pressure 50kPa</td>
<td>98</td>
</tr>
<tr>
<td>4.11</td>
<td>Summary of deviator stress at pre-consolidation pressure 80kPa</td>
<td>100</td>
</tr>
<tr>
<td>4.12</td>
<td>Summary of deviator stress at pre-consolidation pressure 100kPa</td>
<td>102</td>
</tr>
<tr>
<td>4.13</td>
<td>Summary of excess pore water pressure at pre-consolidation pressure 50kPa</td>
<td>105</td>
</tr>
<tr>
<td>4.14</td>
<td>Summary of excess pore water pressure at pre-consolidation pressure 80kPa</td>
<td>108</td>
</tr>
<tr>
<td>4.15</td>
<td>Summary of excess pore water pressure at pre-consolidation pressure 100kPa</td>
<td>110</td>
</tr>
<tr>
<td>4.16</td>
<td>Summary of $\varepsilon_a$, $\sigma_{d\text{max}}$ and $\Delta u_{\text{max}}$ for undisturbed and reconstituted peat</td>
<td>111</td>
</tr>
<tr>
<td>4.17</td>
<td>Effective undrained triaxial summary results</td>
<td>117</td>
</tr>
<tr>
<td>5.1</td>
<td>Summary of physical properties of Parit Nipah peat soil</td>
<td>127</td>
</tr>
<tr>
<td>5.2</td>
<td>Summary of shear strength properties analysis</td>
<td>128</td>
</tr>
<tr>
<td>5.3</td>
<td>Classification of shear strength properties based on fiber content range</td>
<td>130</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

1.1 Peat land in Malaysia (Wetlands International-Malaysia, 2010) 3
2.1 Peat distribution in the world (Trumper et al., 2009) 12
2.2 General distribution of quarternary deposits including peat and soft soils in Peninsular Malaysia (modified after geological map of Peninsular Malaysia, 9th. edition, 2014; CREAM, 2015) 13
2.3 General distribution of quarternary deposits including peat and soft soils in Sabah and Sarawak (modified after geological map Sabah and Sarawak, geological survey of Malaysia, 1992; CREAM, 2015) 13
2.4 Profile morphology of drained organic soil (Mutalib et al., 1992; Rahman and Chan, 2013) 14
2.5 Texture of tropical peat (Wust et al., 2002) 15
2.6 Subsidence rate versus groundwater level relationships for different areas in the world (Wösten et al., 1997; Al-Ani, 2015) 26
2.7 General arrangement of slurry consolidometer (Barnes, 2015) 33
2.8 Variation of cohesion with pre-consolidation pressure (Rabee et al., 2012) 39
2.9 Variation of $\phi$ with pre-consolidation pressure (Rabee et al., 2012) 40
2.10 Effect of degree of humification on shear strength properties 42
2.11 Triaxial compression test apparatus (Teferi, 2011) 43
2.12 Results of stress-strain and excess pore water pressure on undisturbed peat at Parit Nipah (Mohamad, 2015) 46
2.13 Variation of stress strain and pore water pressure relationship  
Das (2007)  
(a) deviator stress against axial strain for loose soil,  
(b) deviator stress against axial strain for dense soil,  
(c) pore water pressure against axial strain for loose soil,  
(d) pore water pressure against axial strain for dense soil

2.14 Pore pressure pattern for undrained peat  
(Gosling and Keeton, 2006)

2.15 Shear strength parameter of total and effective stress failure  
envelopes for consolidated undrained triaxial tests (Das, 2007)

2.16 Failure envelope for undisturbed peat (Mohamad, 2015)

3.1 Methodology flow

3.2 Process of removing top soil

3.3 Illustration of the tube sampler setup condition

3.4 Process to collect undisturbed peat sample

3.5 Drying peat samples retained on sieve

3.6 Peat retained on varied sizes of sieve

3.7 Wet sieving process to obtain reconstituted peat sample

3.8 Placed slurry sample into the remolded sampler

3.9 Remolded sampler preparation equipment (one dimensional consolidation)

3.10 The main steps of the slurry deposition process (Barnes, 2015)  
a) Check the holes and tube does not stuffy,  
b) Pouring the slurry sample slowly on flexible tube,  
c) Raise the flexible tube while pouring the slurry sample,  
d) Fill the slurry sample until full,  
e) Load the slurry sample with pre-consolidation pressure

3.11 Reconstituted peat sampler

3.12 Peat sample for consolidated undrained test

3.13 Moisture content samples

3.14 Cone penetration equipment

3.15 Specific gravity test

3.16 Loss of ignition test
3.17 Sodium hexametaphosphate
3.18 Peat was submerged into hydrochloric acid solution
3.19 Process of fiber content test
3.20 GDS triaxial compression test
3.21 The piston touch the top cap during shearing stage
4.1 Von Post squeezing method
4.2 Particle size distribution of disturbed sample Parit Nipah peat
4.3 Water content versus type of sample
4.4 Liquid limit versus type of sample
4.5 The differences between the usage of kerosene and water
4.6 Specific gravity versus type of sample
4.7 Organic content versus type of sample
4.8 Fiber content versus type of sample
4.9 Typical curve for deviator stress versus axial strain for undisturbed and reconstituted peat at pre-consolidation pressure 50kPa
4.10 Comparison of undisturbed and reconstituted peat at pre-consolidation pressure 50kPa on deviator stress
4.11 Typical curve for deviator stress versus axial strain for undisturbed and reconstituted peat at pre-consolidation pressure 80kPa
4.12 Comparison of undisturbed and reconstituted peat at pre-consolidation pressure 80kPa on deviator stress
4.13 Typical curve for deviator stress versus axial strain for undisturbed and reconstituted peat at pre-consolidation pressure 100kPa
4.14 Comparison of undisturbed and reconstituted peat at pre-consolidation pressure 100kPa on deviator stress
4.15 Excess pore water pressure-strain relationship for undisturbed and reconstituted peat at pre-consolidation pressure 50kPa
4.16 Comparison of undisturbed and reconstituted peat at pre-consolidation pressure 50kPa on excess pore
water pressure

4.17 Excess pore water pressure- strain relationship for undisturbed and reconstituted peat at pre- consolidation pressure 80kPa

4.18 Comparison of undisturbed and reconstituted peat at pre- consolidation pressure 80kPa on excess pore water pressure

4.19 Excess pore water pressure- strain relationship for undisturbed and reconstituted peat at pre- consolidation pressure 100kPa

4.20 Comparison of undisturbed and reconstituted peat at pre- consolidation pressure 100kPa on excess pore water pressure

4.21 Shear stress at failure ($T_f$) against normal stress ($\sigma_n$) for undisturbed sample

4.22 Shear stress at failure ($T_f$) against normal stress ($\sigma_n$) for RS0.425

4.23 Shear stress at failure ($T_f$) against normal stress ($\sigma_n$) for RS1.00

4.24 Shear stress at failure ($T_f$) against normal stress ($\sigma_n$) for RS2.36

4.25 Shear stress at failure ($T_f$) against normal stress ($\sigma_n$) for RS3.35

4.26 Effect of peat size at pre- consolidation pressure 50kPa on effective cohesion and effective angle of friction

4.27 Effect of peat size at pre- consolidation pressure 80kPa on effective cohesion and effective angle of friction

4.28 Effect of peat size at pre- consolidation pressure 100kPa on effective cohesion and effective angle of friction

4.29 Reconstituted sample (passing peat size) against cohesion and angle of friction

4.30 Reconstituted sample (pre- consolidation pressure) against cohesion and angle of friction
### LIST OF SYMBOL AND ABBREVIATION

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
</tr>
<tr>
<td>BS</td>
<td>British Standard</td>
</tr>
<tr>
<td>c</td>
<td>Cohesion value of soil</td>
</tr>
<tr>
<td>c'</td>
<td>Apparent cohesion in term of effective stress</td>
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<tr>
<td>C&lt;sub&gt;c&lt;/sub&gt;</td>
<td>Gradation coefficient</td>
</tr>
<tr>
<td>C&lt;sub&gt;u&lt;/sub&gt;</td>
<td>Uniformity coefficient</td>
</tr>
<tr>
<td>Cu</td>
<td>Undrained shear strength</td>
</tr>
<tr>
<td>CD</td>
<td>Consolidated drained test</td>
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<tr>
<td>CU</td>
<td>Consolidated undrained test</td>
</tr>
<tr>
<td>D&lt;sub&gt;10&lt;/sub&gt;</td>
<td>Effective size at 10%</td>
</tr>
<tr>
<td>D&lt;sub&gt;30&lt;/sub&gt;</td>
<td>Effective size at 30%</td>
</tr>
<tr>
<td>D&lt;sub&gt;60&lt;/sub&gt;</td>
<td>Effective size at 60%</td>
</tr>
<tr>
<td>e&lt;sub&gt;o&lt;/sub&gt;</td>
<td>Void ratio</td>
</tr>
<tr>
<td>g</td>
<td>Gram</td>
</tr>
<tr>
<td>Gs</td>
<td>Specific gravity</td>
</tr>
<tr>
<td>Ha</td>
<td>Hectare</td>
</tr>
<tr>
<td>HCl</td>
<td>Hydrochloric acid</td>
</tr>
<tr>
<td>kN/ m&lt;sup&gt;2&lt;/sup&gt;</td>
<td>KiloNewton per meter square</td>
</tr>
<tr>
<td>kPa</td>
<td>Kilopascal</td>
</tr>
<tr>
<td>LL</td>
<td>Liquid limit</td>
</tr>
<tr>
<td>LOI</td>
<td>Loss on Ignition</td>
</tr>
<tr>
<td>M</td>
<td>Mass</td>
</tr>
<tr>
<td>m</td>
<td>Meter</td>
</tr>
<tr>
<td>ml</td>
<td>Millilitre</td>
</tr>
<tr>
<td>mm</td>
<td>Millimeter</td>
</tr>
<tr>
<td>mg/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Milligram per cubic meter</td>
</tr>
</tbody>
</table>
O - Organic
Pt - Peat
PVC - Polyvinyl Chloride
RECESS - Research Centre for Soft Soils
RS - Reconstituted peat
S_u - Undrained shear strength
UCS - Unconfined Compressive Strength Test
UD - Undisturbed peat
USCS - Unified Soil Classification System
USDA - United States Department of Agriculture
UTHM - Universiti Tun Hussein Onn Malaysia
UU - Unconsolidated undrained test
μm - Micrometer
ε_a - Axial strain
σ_dmax - Maximum deviator stress
w - Water content
% - Percentage
ϕ - Angle of internal friction
ϕ' - Angle of internal friction based on effective stress
τ - Shear stress
τ_f - Shear strength at failure
τ_f' - Effective shear strength at failure
Δu - Excess pore water pressure
σ_c - Pre-consolidation pressure
σ' - Normal stress on the failure plane based on effective stress
σ_n - Normal stress
μm - Micrometer
° - Degree
ρk - Density of the kerosene (mg/ms)
CHAPTER 1

INTRODUCTION

1.1 Background Study

Peat soil is formed when a decay process of plants is produced and it is divided into three categories namely hemic peat, fibric peat and sapric peat. The difference between peat and inorganic soil leads to difference in the physical and mechanical properties such as high compressibility. During the sampling process and specimen test, the peat soil sample preparation undergoes a careful process. This is because of the structure of fibrous peat has a high compressibility, especially when dealing with low peat decomposition. Physical properties of peat can represent the structure and engineering properties (MacFarlane and Radforth, 1965; and Zainorabidin and Bakar, 2003). Peat is a problematic soil in terms of stability and long term settlement.

Generally, peat soil can be described as soil that is formed by the dead wetland materials that cannot decay in a normal way because of the presence of high water table. When the organic matter decomposed, it turns into a sort of glue called humus, which is strong enough to bind several smaller particles together, making them into larger multi-particles, which can alter the behavior of the soil (Paikowsky et al., 2003). Additionally, organic matter also contains products of microbial synthesis which includes (CREAM, 2015):
i. Fresh plant and animal residues (decomposable)

ii. Humus (resistant)

iii. Inert forms of nearly elemental carbon (charcoal, coal or graphite)

Table 1.1 shows the proportionate distribution of peat across the states in Malaysia. There are about 2.5 million hectares of peatland in Malaysia including 0.7 million hectares of peat soil in Peninsular Malaysia, 1.7 million hectares in Sarawak and 0.2 million hectares in Sabah (Wetlands International Malaysia, 2010 and CREAM 2015). The state of Sarawak has the largest areas of peat soils that amounted to 1,697,847 hectares, followed by Peninsular Malaysia with 642,918 hectares; then followed by Sabah which recorded 116,965 hectares, with the percentage of total peatland area are 69.08%, 26.16% and 4.76% respectively.

Figure 1.1 shows the locations where peat located in Malaysia. The shaded area shows the distribution of peat in Malaysia. Based on Figure 1.1, the largest peatland in Malaysia is located in Sarawak with 16,500 km². In Peninsular Malaysia, the peat areas are found in the east and west coast areas, especially in the coastal areas of West Johore, Kuantan and Pekan district, Rompin-Endau area, Northwest Selangor and the Perak (Hilir Perak district and Perak Tengah district). In Sarawak, peat occurs mainly between the lower stretches of the poorly drained interior valleys (valley peat) and the main river course (basin peat). Peat is found in the administrative division of Sri Aman, Sibu, Sarakei, Bintulu, Miri, Kuching, Samarahan and Limbang. In Sabah, the organic soils are found around the coastal areas of the Klias peninsula, Krah swamps in Sugut, Kota Belud and Labuk estuaries and Kinabatangan floodplains (Phillips, 1998).

Table 1.1: Proportionate distribution of peat in Malaysia
(Wetlands International Malaysia, 2010; and CREAM, 2015)

<table>
<thead>
<tr>
<th>Regions</th>
<th>Total peat area (ha)</th>
<th>Percentage of total peatland area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peninsular</td>
<td>642,918</td>
<td>26.16</td>
</tr>
<tr>
<td>Sabah</td>
<td>116,965</td>
<td>4.76</td>
</tr>
<tr>
<td>Sarawak</td>
<td>1,697,847</td>
<td>69.08</td>
</tr>
<tr>
<td>Total (ha)</td>
<td>2,457,730</td>
<td></td>
</tr>
</tbody>
</table>
Peat soils have higher moisture content and wet density values that are approximately equal to the water density value. Classification of the decomposition proposed by Von Post (1922) was divided into ten groups, H1 to H10. The values represent the degree of decomposition are increasing as the number of classification increase. According to this system, test samples are classified into H3 and H6 with an average organic content of 75% and 30%, respectively. H3 refers to very slightly
decomposed peat, which releases very muddy brown water when being squeezed but no peat passes through the fingers. The remaining plants are still identifiable and no amorphous material is present. H6 refers to moderately decomposed peat with a very indistinct plant structure. When it is squeezed, about one-third of the peat escapes between the fingers and the structure is more distinct compared to before squeezing. The symbol of Peat is ‘Pt’ and grouped into the soil at the rate of two high organic (organic soil). Based on Mankinen and Gelfer (1982), peat is a soil with organic content greater than 50%, but according to Landva et al., (1983); Kearns and Davison (1983); and ASTM D4427 (2013), peat is a soil with organic content more than 75%. Whitlow (2001) and Jelisic and Leppanen (2003) stated that peat has a low bearing capacity in the range 5kPa – 20 kPa which is lower than the soft clay, so the result can cause a slide / collapse (bearing capacity failure) due to low shear strength and high settlement due to high compressibility characteristic of peat. Hence, construction over peat deposit may cause excessive settlement and bearing capacity failure.

1.2 Problem Statement

In construction, there is problem rises on peat soil since it lacks of strength which contributes to ground failure. In order to overcome this problem, ground improvement and alternative methods need to be executed and these certainly gain added costs for development. Nevertheless, the challenge on the peats is the difficulty to collect undisturbed peat samples that truly represent site conditions due to the soil condition and its properties (Munro, 2004). Whitlow (2001) stated that is actually it most impossible to gain a totally undisturbed sample of soft soil because of the process of boring, driving the coring tool, raising and withdrawing the coring tool and extruding the sample from the coring tool which caused some disturbance in the structure of the soft soil. Hence, the knowledge and deeper understanding on forming reconstituted samples and engineering parameters of peat soil is needed to overcome this study.

Peat soil is highly problematic because the traits that originally led to the weak of the soil is due to the low undrained shear strength in normally consolidated state and low bearing capacity under the foundation which cause it is not
recommended in construction by some developers (Gofar and Sutejo, 2007). Construction on peat soil nowadays increasing rapidly because of the lack space on the suitable land. Due to this rapid urban development the land owner and developers are forced to open a new space area. Due to this phenomenon the construction of infrastructure like building, highway and other construction have to be constructed on the organic soil. There are various construction techniques that have been carried out to support embankments over peat deposits without risking bearing failures but settlement of these embankments remains excessively large and continues for many years. Thus, the active and effective research has to be conducted to find and understand the best solution on this phenomenon to overcome this problem.

Generally, peat commonly occur as extremely soft, wet, unconsolidated surficial deposits that are an integral part of wetland systems. These types of soils contribute to geotechnical problems in the area of sampling, settlement, stability, in situ testing, stabilization and construction. Formation of peat significantly takes time to fully decompose. It will decompose from fibrous (least decomposed) to hemic (intermediate decomposed) and then settle down as sapric (most decomposed). The degree of peat decomposition will contribute to the changing of peat fiber, thus it affects to the changing of engineering properties such as shear strength properties. The different sizing of peat fiber will result in different shear strength properties. Hebib (2001) has revealed that least decomposed peat has higher shear strength rather than most decomposed peat due to the presence of large fiber in the peat acts as reinforcement.

Peat also contains high water content because of the high presence of hollow pore in the fiber itself. Due to this condition, it may affect the strength of the peat. To remove the water content from peat soil, the pre-consolidation slurry method is suitable to be applied in this study. Pre-consolidation slurry method is a very popular method to drain out the excessive water content from the soil specimen. This method is popular conducted by researchers to form the reconstituted samples from slurry samples. Barnes (2015), Anggraini (2006) and Rabbee et al., (2012) has figured that the reconstitution specimen is one of the great techniques in the laboratory to obtain element testing of repeatable and homogenous test samples. Anggraini (2006) conducted reconstituted sample on fibrous peat at Pontian Johor. The peat sample was consolidated with pre-consolidation pressure (50kPa, 100kPa, 150kPa and 200kPa) to test the sample on the triaxial Unconsolidated Undrained
Triaxial Test (UU- Test). The result of shear strength properties (cohesion and angle of friction) of reconstituted peat increased, due to the increase of the pre-consolidation pressure. Differ from this thesis, the author conducted the reconstituted peat on Parit Nipah peat that classified as hemic peat. The reconstituted peat sample through segregation peat size via wet sieving and consolidated with the 50kPa, 80kPa and 100kPa pre-consolidation pressure to test the specimen on the Consolidated Undrained Triaxial Test (CU- Test).

1.3 Research Objectives

The aim of this study was to determine the effective undrained shear strength properties of reconstituted peat. Therefore, the shear strength properties (c’ and φ’) need to investigate to correlate with the effect of the reconstituted method (peat size and pre-consolidation pressure). To achieve the outcomes, the objective was highlighted

The specific objectives of this thesis are:
1) To determine the physical properties of undisturbed and reconstituted peat.
2) To investigate the shear strength parameters of undisturbed and reconstituted peat of different sizes of peat and in different pre-consolidation pressure.
3) To correlate the shear strength properties with the effect of passing peat size and pre-consolidation pressure.

1.4 Scope of Research

The scope of this study is about to investigate the shear strength properties of reconstituted peat sample. Peat samples are obtained from Parit Nipah, Johor. The samples were taken at depth of about 0.3m – 1.0m (depends on the existing of ground water table) from surface level. The samples were divided into two samples that are disturbed sample and undisturbed sample. The disturbed peat samples were obtained to reconstruct peat as reconstituted peat sample meanwhile; undisturbed peat samples were obtained in this study as a comparison sample with reconstituted peat samples. The physical properties test was also performed in this study such as moisture content, liquid limit, organic content, fiber content and specific gravity. All
tests were conducted according to British Standard Institution (BS 1377: 1990), Manual of Soil Laboratory Testing by Head and Annual Book of ASTM Standards.

All the peat samples were brought to the RECESS, UTHM to proceed with the physical and mechanical test. The disturbed peat samples were sieved through wet sieves with different sizes of sieve opening to obtain the reconstituted samples. In this project the reconstituted peat samples were prepared through four different sizes that are 0.425mm, 1.000mm, 2.360mm and 3.350mm. Reconstituted peat samples were formed by using a pre-consolidation pressure of 50kPa, 80kPa and 100kPa that represent the pressure at the site that can be exerted on a soil without irrecoverable volume change. Johari et al. (2014) stated the value for pre-consolidation pressure for Parit Nipah peat is 26kPa at the depth 0.3m to 1.0m.

In this study, the Consolidated Undrained Triaxial Compression Shear Test (CU-Test) was applied on the specimens of diameter 50mm and 100mm height and was subjected to confining pressure of 25 kPa, 50 kPa and 100 kPa. This pressure was performed to represent peat depth layers where average stress has been carried by the soil and simulate as the real site pressure condition (Mohamad, 2015). The results that obtained from the triaxial test were analyzed to understand the shear strength properties by determining the effective cohesion (c’) and effective angle of friction (ϕ’). The standard for triaxial compression test (BS 1377-8: 1990) was used to determine the shear strength properties (effective stress). Subsequently, the shear strength properties results that obtained for both undisturbed and reconstituted samples were correlated with the sizes of peat and pre-consolidation pressure.

1.5 Significance of Research

A sound scientific understanding of the nature and functions of peat and organic soils is critical to their correct and safe use, and this research contributes by offering students, researchers, engineers and academics involved with these types of soils a comprehensive overview. In the principle of the shear strength, the effective cohesion (c’) and effective angle of friction (ϕ’) are the shear strength parameters. These parameters are very important and it is necessary to determine these values to design the retaining structures, foundation, slope and other structures. Therefore, in-
depth knowledge regarding the shear strength parameters is necessary because it is very useful to engineers to design safe structures.

This research is very useful to geotechnical engineering and who is involved in the development of peat lands. In the future, the developers and contractors can determine the soil shear strength properties in a variety of peat size, degree of decomposition, fiber content, organic content and others data that offers in this study by referring the data value obtained and thus can be used in preliminary work in construction. This study may also help researchers in the shear strength determination at certain of peat size with the classification of peat. For example, when the researchers go to the construction areas and determine the type of peat whether fibric, hemic and sapric by using the Von Post method, thus the researchers can evaluate and relate the range value of shear strength from the data that were obtained in this study. Apart from that, this data will also help the peat researchers in the future who work on with the distribution of soil, where to refer directly to the shear strength data on different sizes obtained from this study without having to make consolidated- undrained test and maybe can proceed with the other test experiment.

Hopefully, in the future, more peat researchers study about shear strength peat in term of the peat size passing through a wet sieve to obtain more shear strength data.

1.6 Structure of Thesis

The entire thesis chapter consists of five chapters and outlined in Table 1.2. Chapter 1 consists of the project background, problem statement, aim, objectives, scope and significance of the study. Chapter 2 contains literature review that summarises some information about the study that can be related to the topic subject like physical properties of peat, wet sieve method and shear strength parameters that can relate with the pre- consolidation loads. Chapter 3 consists of the research methodology and explanation in detail about the soil sample preparation procedure, test apparatus and equipment, materials, data acquisition and processing methods used. In Chapter 4, the test results were analyzed and presented in table and graph, where soil classification, properties of peat soils and shear strength are discussed in detail. The
last chapter summarised all the results and recommendation for future work based on current study experience and literature review.

Table 1.2: Thesis outline

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction</td>
<td>Project introduction including aim, objective and scopes of study</td>
</tr>
<tr>
<td>2</td>
<td>Literature Review</td>
<td>Reviews the literature relating to the research, which includes soil properties/ characteristics, materials, and laboratory testing.</td>
</tr>
<tr>
<td>3</td>
<td>Research Methodology</td>
<td>Materials and experimental work in terms of sample preparation, test equipment, and procedure is described. This section discusses a developed laboratory testing technique which is considered necessary in the site for successful field implementation.</td>
</tr>
<tr>
<td>4</td>
<td>Result and Analysis</td>
<td>Results and discusses the findings of this study. This include soil identification and classification, physical and engineering properties including shear strength properties.</td>
</tr>
<tr>
<td>5</td>
<td>Conclusion and Recommendation</td>
<td>Conclude all the results gained in chapter 4. Link all the result with the objective proposed in Chapter 1. List suggestions for future studies.</td>
</tr>
</tbody>
</table>
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Nowadays, the construction development over peat soil is increasing due to the lack of space and suitable land for building infrastructure, highway construction and other development. The problems of peat in foundation construction generally is because of its own characteristics such as low shear strength, very high natural moisture content, high compressibility and water holding capacity, low specific gravity and low bearing capacity (Kazemian et al., 2011).

The problems of peat can be solved using soil improvement method such as soil replacement, water removal, site strengthening, thermal and geosynthetics. The water removal method can be divided into four categories which are trenching, electroosmosis, pre-compression without vertical drain and pre-compression with vertical drain. In Malaysia, pre-compression with vertical drain method is popular to remove the water from the soil (Yusoff, 2015). Vertical drains concept artificially-created drainage paths which installed by one of several method and can have a variety of physical characteristics. Vertical drains installation also used in order to accelerate settlement and gain in strength of peat soil. A proper understanding of the shear strength properties of peat soil is an important element in the solution of the soft soil problems especially on strengthening the ground. In this regard, understanding and determining the laboratory element testing that can represent or mimic the field conditions plays an important role in characterising soil behaviour. On top of that, the selection of the reconstituted method is very important to gain
uniformity and repeatability specimens that can simulate the study area ground strength.

In this chapter, the literature review and the information on properties peat soil samples and obtaining the shear strength parameter are discussed according to the objectives of this research. The information gathered is obtained from journals, books, proceedings and reports.

2.2 Peat

There is about thirty million hectares of peat soil coverage around the world with Canada and Russia having the largest distribution of peat (Zainorabidin, 2010). More than sixty percent of the world’s tropical peat lands are found in South-East Asia (Lette, 2006). Most notable are the large peat land on the islands of Borneo belonging to Indonesia, Malaysia, Brunei and Indonesia. However, there are also significant occurrences in other parts of Indonesia, Malaysia, Vietnam, Thailand and the Philippines (Adon et al., 2012). Figure 2.1 shows the picture of peat distribution around the world which shows that the percentage distribution of peat is in the range 0% to more than 10%. Malaysia is in the range 5% to more than 10% as shown in the red circle areas. Figure 2.2 and Figure 2.3 displays the distribution of quaternary soil around Peninsular Malaysia, Sabah and Sarawak areas. The yellow color areas show the distribution of peat, soft soils, clay, silt, sand and gravel in both figures.

The tabulated data in Table 2.1 shows the distribution of peatland in Malaysia at several states that was listed by (CREAM, 2015). In Peninsular Malaysia, Selangor recorded the highest distribution area of peat and the smallest distribution area was recorded by Negeri Sembilan. Johor has recorded the third largest area of peat distribution after Pahang and Selangor with the total area 143, 974 hectares. However, the distribution of peat in Sarawak has recorded the largest distribution of peat area with 1, 697, 847 hectares followed by Sabah and the Peninsular Malaysia with 116, 965 hectares and 642, 918 hectares respectively. Overall, the total distribution area of peatland in Malaysia is about 2, 457, 730 hectares.
Table 2.1: Distribution area of peat in Malaysia (CREAM, 2015)

<table>
<thead>
<tr>
<th>State</th>
<th>Total Area of Peat (Ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Johor</td>
<td>143,974</td>
</tr>
<tr>
<td>Pahang</td>
<td>164,113</td>
</tr>
<tr>
<td>Selangor</td>
<td>164,708</td>
</tr>
<tr>
<td>Perak</td>
<td>69,597</td>
</tr>
<tr>
<td>Terengganu</td>
<td>84,693</td>
</tr>
<tr>
<td>Kelantan</td>
<td>9,146</td>
</tr>
<tr>
<td>Negeri Sembilan</td>
<td>6,245</td>
</tr>
<tr>
<td>Federal Territory</td>
<td>381</td>
</tr>
<tr>
<td>Sabah</td>
<td>116,965</td>
</tr>
<tr>
<td>Sarawak</td>
<td>1,697,847</td>
</tr>
<tr>
<td>Total</td>
<td>2,457,730</td>
</tr>
</tbody>
</table>

Figure 2.1: Peat Distribution in the World (Trumper et al., 2009)
Figure 2.2: General Distribution of Quaternary Deposits including Peat and Soft Soils in Peninsular Malaysia (modified after Geological Map of Peninsular Malaysia, 9th. Edition, 2014; CREAM, 2015)

Figure 2.3: General Distribution of Quaternary Deposits including Peat and Soft Soils in Sabah and Sarawak (modified after Geological Map Sabah and Sarawak, Geological Survey of Malaysia, 1992; CREAM, 2015).
Figure 2.4 illustrate the profile morphology of peat structure. The arrangement of particle seen loose in fibric peat compared to the sapric peat because of the presence of woody plant. Figure 2.5 shows the texture of tropical peat. As can be seen, the colour of peat soil in Malaysia is generally dark reddish brown to black. It consists of loose, branches, partly decomposed leaves, twigs and tree trunks with a low mineral content (Wust et al., 2002). The formation of peat is mainly controlled by the combination of water and temperature. On earth, temporal and spatial changes of water and temperature depend upon climatic conditions, and geological, geomorphologic, and hydrological factors. These factors directly and indirectly influence peat formation, development, and its characteristics.

Figure 2.4: Profile Morphology of drained organic soil (Mutalib et al., 1992; Rahman and Chan, 2013)
Figure 2.5: Texture of Tropical Peat (Wust et al., 2002)

Peat originates from plants and denotes the various stages in the humification process where the plant structure can be discerned (Hartlen and Wolski, 1996; CREAM, 2015). Peat is partially or totally decomposed remains of dead plants which have accumulated under water for tens to thousands of years. Based on Zainorabidin and Wijeyesekera (2007), peat soil is generally originated from the plant and animal remains. According to Kazemian et al. (2011), peat soil composed of high content of
fibrous organic matters and was produced by the partial decomposition and disintegration of mosses, sedges, trees and other plants that grow in marshes and other wet place in the condition of lack of oxygen. At the same time, peat is a mixture of fragmented organic material formed in wetlands under appropriate climatic and topographic conditions and it is derived from vegetation that has been chemically changed and fossilized (Edil and Dhowian, 1981; Mesri and Ajlouni, 2007). Decomposition or humification involves the loss of organic matter either in gas or in solution, the disappearance of the physical structure and the change in the chemical state (Huat et al., 2009).

In natural state, peat consists of water and decomposed plant fragment with virtually no measurable strength (Munro, 2005). Table 2.2 shows the description and determination of peat from peat researchers. As concluded, peat is a mixture of fragmented organic material forms where the lack of oxygen prevents natural microorganisms from decomposing the dead plant material. Thus, peat is considered unsuitable for supporting foundations in its natural state.

Peat represents the extreme form of soft soil. It is an organic soil, which consists more than 75% of organic matters (Huat et al., 2014). The organic content of peat is basically the remains of plant for which rate of accumulation is faster than the rate of decay. The content of peat differs from location to location due to the factor such as the origin fiber, temperature and humidity (Huat, 2004). The definition of peat soil depends on the purpose or the field of application that is shown in Table 2.3. Based on USDA (Soil Taxonomy) and Zainorabidin (2010), the purpose of application from agriculture and soil science perspectives, peat is defined with organic content more than 20% and 35% respectively. Meanwhile, from the geotechnical engineering purpose, the organic content below than 75% is known as organic soil, otherwise is known as peat.
Table 2.2: Summary description and determination of peat soil

<table>
<thead>
<tr>
<th>Name</th>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edil and Dhowian</td>
<td>1981</td>
<td>Peat is a mixture of fragmented organic material formed in wetlands under appropriate climatic and topographic conditions and it is derived from vegetation that has been chemically changed and fossilized.</td>
</tr>
<tr>
<td>Jarret</td>
<td>1995</td>
<td>Peat is an organic soil which consist more than 70% of organic matters. Peat deposits are found where conditions are favorable for their formation.</td>
</tr>
<tr>
<td>Hartlen and Wolski</td>
<td>1996</td>
<td>Peat originates from plants and denotes the various stages in the humification process where the plant structure can be discerned.</td>
</tr>
<tr>
<td>Munro</td>
<td>2004</td>
<td>Peat forms where the lack of oxygen prevents natural micro-organisms from decomposing the dead plant material. Peat forms slowly involving an accumulation of organic materials in water, and taking approximately 10 years for 1cm of peat to form.</td>
</tr>
<tr>
<td>Duraisamy et al.,</td>
<td>2007</td>
<td>Peat is considered unsuitable for supporting foundations in its natural state</td>
</tr>
<tr>
<td>Kazemian et al.,</td>
<td>2011</td>
<td>Peat soil composed of high content of fibrous organic matters and is produced by the partial decomposition and disintegration of mosses, sedges, trees and other plants that grow in marshes and other wet place in the condition of lack of oxygen.</td>
</tr>
</tbody>
</table>

Table 2.3: General purpose definition of peat

<table>
<thead>
<tr>
<th>Purpose of application</th>
<th>Definition</th>
<th>From reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geotechnical engineering</td>
<td>Organic content $&lt; 75%$ = organic soil Organic content $&gt; 75%$ = peat</td>
<td>ASTM D4427-92</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Organic content $&gt; 20%$ = peat</td>
<td>USDA (Soil Taxonomy)</td>
</tr>
<tr>
<td>Soil science</td>
<td>Organic content $&gt; 35%$ = peat</td>
<td>USDA (Soil Taxonomy)</td>
</tr>
</tbody>
</table>

2.3 Classification of Peat

The physical, chemical, and geotechnical characteristics commonly used for classification of inorganic soil may not be applicable to the characterization of peat. On the other hand, properties which are not pertinent to inorganic soil may be important for classification of peat. Furthermore, the range values applied for some properties of inorganic soil may not be relevant for peat. Generally, the classification
of peat is developed based on the decomposition of fiber, the vegetation forming the organic content, and fiber content.

Table 2.4 shows the classification of peat according to degree of humification. The classification of peat soils have been classified into 10 groups (H1-H10) by Von Post based on water content, fibre properties, and degree of decomposition (Von, 1922). The test was conducted by pressing the peat soil in the hand and it gives off marked muddy water. The pressed residue material remaining in the hand has fibrous structure and it is some-what thick. Based on (Hartlen and Wolski, 1996), the fibrous peat with more than 60% fiber content is usually in the range of H1 to H4.

To a geotechnical engineer, all soils with organic content of greater than 20% is known as organic soil. Peat soil is an organic soil with organic content of more than 75% (Huat, 2004). This classification is partly the same as ASTM D 2487-06 classifications; a soil with organic content less than 75% (or ash content more than 25%) as muck or organic soil, while a soil with organic content higher than 75% (or ash content less than 25%) as a peat. For geotechnical purposes, degree of peat decomposition or humification system of Von Post is often divided into 3 classes that are (Magnan, 1980; ASTM Standard D 5715-00):

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

Davis (1997) said that peat is classified as woody, fibrous, sedimentary, and granular peat in terms of texture. In Malaysia, Malaysian Soil Classification System (MSCS) also had been introduced to classify organic soil and peat. The MSCS is developed based on British Soil Classification (BS 5930: 1981) and improved by Public Work Malaysia. MSCS used the degree of humidification as another parameter to classify the state of decay of organic soil after organic content.

Fiber content is also included in the system as the third factor to be considered for classifying the organic soil. The additional factors introduced into the system have provided better description and information about organic soil in
Malaysia (Zainorabidin et al., 2007). Generally, the classification of peat is developed based on the decomposition of fiber, the vegetation forming the organic content, and fiber content. Based on Jarret (1995), the soil classification of organic soil can be determined as shown in Table 2.5 and Table 2.6. The features of the physical properties determination with the definitions and significance of the tests is summarised in Table 2.7. The physical properties accommodate the valuable information in determining the peat classification.

Table 2.4: Peat classification according to degree of humification (Von, 1992 and Adon et al., 2012)

<table>
<thead>
<tr>
<th>Degree of Decomposition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>Fibric</td>
</tr>
<tr>
<td></td>
<td>Completely undecomposed peat which releases almost clear water. Plant remains easily identifiable. No amorphous material present.</td>
</tr>
<tr>
<td>H2</td>
<td>Hemic</td>
</tr>
<tr>
<td></td>
<td>Almost completely undecomposed peat which releases clear or yellowish water. Plant remains still easily identifiable. No amorphous material present.</td>
</tr>
<tr>
<td>H3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>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 material present.</td>
</tr>
<tr>
<td>H4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slightly decomposed peat which, when squeezed, releases very muddy dark water. No peat is passed between the fingers, but the plant remains are slightly pasty and have lost some of their identifiable features.</td>
</tr>
<tr>
<td>H5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderately decomposed peat which, when squeezed, releases very “muddy” water with a very small amount of amorphous granular peat escaping between the fingers. The structure of the plant remains is quite indistinct although it is still possible to recognize certain features. The residue is very pasty.</td>
</tr>
<tr>
<td>H6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderately decomposed peat which a very indistinct plant structure. When squeezed, about one-third of the peat escapes between the fingers. The structure more distinctly than before squeezing.</td>
</tr>
<tr>
<td>H7</td>
<td>Sapric</td>
</tr>
<tr>
<td></td>
<td>Highly 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.</td>
</tr>
<tr>
<td>H8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Very highly decomposed peat with large quantity of amorphous material with very 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.</td>
</tr>
<tr>
<td>H9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Practically fully decomposed peat in which there is hardly any recognizable plant structure. When squeezed it is a fairly uniform paste.</td>
</tr>
<tr>
<td>H10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Completely decomposed peat with no discernible plant structure. When squeezed, all the wet peat escapes between the fingers.</td>
</tr>
</tbody>
</table>
Table 2.5: Organic soil classification based on the organic content (Jarret, 1995)

<table>
<thead>
<tr>
<th>Soil Types</th>
<th>Description</th>
<th>Symbol</th>
<th>Organic Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay or silt or sand</td>
<td>Some Organic</td>
<td>O</td>
<td>2-20</td>
</tr>
<tr>
<td>Organic Soil</td>
<td>-</td>
<td>O</td>
<td>25-70</td>
</tr>
<tr>
<td>Peat</td>
<td>-</td>
<td>Pt</td>
<td>&gt;75</td>
</tr>
</tbody>
</table>

Table 2.6: Classification based on the fiber content of peat (Jarret, 1995)

<table>
<thead>
<tr>
<th>Soil Types</th>
<th>Fiber Content</th>
<th>Degree of Humification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibric Peat</td>
<td>&gt;66%</td>
<td>H₁-H₃</td>
</tr>
<tr>
<td>Hemic Peat</td>
<td>33%-66%</td>
<td>H₄-H₆</td>
</tr>
<tr>
<td>Sapric Peat</td>
<td>&lt;33%</td>
<td>H₇-H₁₀</td>
</tr>
</tbody>
</table>

Table 2.7: Definition and significance of the test

<table>
<thead>
<tr>
<th>Test</th>
<th>Definition</th>
<th>Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree of Humification</td>
<td>The physical appearance of soil was described based on the Von Post classification.</td>
<td>A detail description on classification of soil by refer H₁-H₁₀ classification of peat</td>
</tr>
<tr>
<td>Particle Size Distribution</td>
<td>The list of values that defines as the relative amount, typically by mass, of particles present according to size.</td>
<td>To determine the percentage of various sized soil particles in a soil mass. The findings of the results allow the particle size distribution curve is plotted</td>
</tr>
<tr>
<td>Moisture Content</td>
<td>The ratio of the mass of water in a specimen to the mass of solid in the specimen.</td>
<td>The percentage of moisture content can be related to the settlement, shear strength and compressibility of the soil.</td>
</tr>
<tr>
<td>Liquid Limit</td>
<td>The water content at which soil passes from the plastic to the liquid state.</td>
<td>The limit is expressed as a percentage of the dry weight of the soil.</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>Specify the ratio of the weight of a given volume of the material to the mass of an equal volume of water.</td>
<td>It is related to the degree of decomposition and mineral content of peat.</td>
</tr>
<tr>
<td>Organic Content</td>
<td>The organic content is the percentage of the organic matter present in a soil.</td>
<td>Important parameter whereby the percentage of peat and organic soils can be indistinguishable</td>
</tr>
<tr>
<td>Fiber Content</td>
<td>Determined typically from dry weight of fiber retained on 0.15 mm as a percentage of oven-dried mass</td>
<td>The percentage of fiber content is used to classified the peat decomposition range.</td>
</tr>
</tbody>
</table>
2.4 Particle Size Distribution

The Unified Soil Classification System (USCS) is the most widely used soil classification system practice in the geotechnical engineering. The purpose of this system is for classifying mineral and organic soil based on the particle size and limit (liquid and plastic) determination. The grain size distribution of a soil determines the governing particle-level forces, inter-particle packing and the ensuing macro scale behavior, while grain shape was established at three different scales: the global form, the scale of major surface features and the scale of surface roughness (Tang, 2011). Santamarina and Cho (2004) reported that each scale reflects the features of the formation history and particles in deciding the global behaviour of the soil mass, from particle packing to mechanical response.

Boelter (1968) has stated that the physical properties of peat are highly affected by the distribution of the pore size and the porosity. These two parameters are related to the distribution of peat size. The degree of decomposition affects the porosity of peat and the porosity is affected by both the particle size and structure of peat. With an increment in the degree of decomposition, the particle size of organic matters decreases Boelter (1968).

In particle size distribution, the uniformity coefficient ($C_u$) and gradation coefficient ($C_c$) are taken into account to determine and verify the grade of soil. A well graded known as a soil that has a broad distribution of particle size, while poorly graded or uniform soils are composed of a narrow size particle distribution only. $C_u > 5$ accounted as a well-graded soil, $C_u < 3$ demonstrate a uniform soil, $C_c$ between 0.5 and 2.0 reveal a well-graded soil and $< 0.1$ indicates a possible gap-graded soil (Das, 2011).
2.4.1 Distribution of Peat Size

ASTM (D2487-06) classified the soil in three major soil divisions: coarse- grained, fine grained and highly organic soil as tabulated in Table 2.8. The peat soil was described and categorized in highly organic soils with the symbol ‘Pt’. Peat is different with other types of soils because the identification of this type of soil is identified through organic matter, colour and odour.

Based on Levesque and Dinel (1977), particle- size distribution of peat fiber was determined according to the wet sieving method. For the case of organic soils, particles size distribution is not necessarily used in characterization and it is highly influenced by its botanic nature. As for mineral soil, the theory of particle composed of single grain unit is not able to be visualized in an organic area. Therefore, it could be practical to use particle size as the comparison for fibrous and non-fibrous peat materials which denote their decomposition level. Wet sieving is chosen to separate fine grains from the coarse grains and it is carried out onto the disturbed or undisturbed soil by using tap water with the arrangement of a stack of aperture sizes which chosen. Said and Taib (2009) has specified their opinion that to obtain the particle size distribution result precisely, the wet sieving analysis must be done on the soil in order to further break the soil particles into a smaller size. Kalantari and Prasad (2014) stated that, tropical peat soils are normally having sizes between 0.006mm to 5.000mm.

Tang (2011) revealed the wet method for coarse peat soil is more effective to practice and the soil fraction finer than 63 µm was analyzed with diffraction laser method (CILAS test). Mohamad (2015) stated the coefficient of curvature (C_c) for peat soil at Parit Nipah Johor is 1.07 and coefficient of uniformity (C_u) is 9.6. In regard of that, with referring to the Unified Soil Classification System (USCS), Parit Nipah peat is classified as well- graded soil and behaves in various shapes and sizes.
<table>
<thead>
<tr>
<th>Major Divisions</th>
<th>Group Symbol</th>
<th>Typical Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>Course-Grained Soils</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravels 50% or more of course</td>
<td>GW</td>
<td>Well-graded gravels and gravel-sand mixtures, little or no fines</td>
</tr>
<tr>
<td>Gravels with Fines</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sands 50% or more of course</td>
<td>GP</td>
<td>Poorly graded gravels and gravel-sand mixtures, little or no fines</td>
</tr>
<tr>
<td>Sands with Fines</td>
<td>GM</td>
<td>Silty gravels, gravel-sand-silt mixtures</td>
</tr>
<tr>
<td>Sands with Fines</td>
<td>GC</td>
<td>Clayey gravels, gravel-sand-clay mixtures</td>
</tr>
<tr>
<td>Clean Sands</td>
<td>SW</td>
<td>Well-graded sands and gravelly sands, little or no fines</td>
</tr>
<tr>
<td>Clean Sands</td>
<td>SP</td>
<td>Poorly graded sands and gravelly sands, little or no fines</td>
</tr>
<tr>
<td>Silts and Clays</td>
<td>SM</td>
<td>Silty sands, sand-silt mixtures</td>
</tr>
<tr>
<td>Silts with Fines</td>
<td>SC</td>
<td>Clayey sands, sand-clay mixtures</td>
</tr>
<tr>
<td>Fine-Grained Soils</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silts and Clays</td>
<td>ML</td>
<td>Inorganic silts, very fine sands, rock four, silty or clayey fine sands</td>
</tr>
<tr>
<td>Silts and Clays</td>
<td>CL</td>
<td>Inorganic clays of low to medium plasticity, gravelly/sandy/silty/lean clays</td>
</tr>
<tr>
<td>Silts and Clays</td>
<td>OL</td>
<td>Organic silts and organic silty clays of low plasticity</td>
</tr>
<tr>
<td>Highly Organic Soils</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pt</td>
<td></td>
<td>Peat, muck, and other highly organic soils</td>
</tr>
</tbody>
</table>

Keyword: Prefix: G= Gravel, S= Sand, M= Silt, C=Clay, O= Organic
Suffix: W= Well Graded, P= Poorly Graded, M= Silty, L= Clay, LL < 50%, H= Clay, LL > 50%
2.5 Physical Properties of Peat

There are a few unique physical properties of peat which should be paid attention in discussion. Hobbs (1986) stated that the physical characteristics such as color, degree of humification, water content and organic contents should be included in a full description of peat. They are influenced by main component of the formation such as mineral content, organic content, moisture and air. When one of these components changes, it will result in the changes of the whole physical properties of peat. Table 2.9 shows the all the physical properties peat data that were recorded from the past researchers in Malaysia.

Boelter (1968) reported that the physical properties of peat are highly affected by the porosity and the distribution of the pore size. Both of these parameters are related in the distribution of peat size. Rahman (2015) stated the degree of decomposition affects the porosity of peat and the porosity is influenced by the particle size and structure of peat. With an increase of the decomposition level, thus it tends to the particle size of organic matters decreases. Past researchers have reported that the degree of decomposition for Parit Nipah peat is H5 (moderately decomposed peat) with the organic and fiber content is in the range between 78 - 93% and 40 - 67% respectively, as tabulated in Table 2.9.

The water content is the most important criteria properties for peat soil. The value of water content depends on the origin, degree of decomposition and the chemical composition of peat (Rahman and Chan, 2014). Generally, peat has very high natural water content due its ability to holding water capacity. Mesri and Ajlouni (2007) emphasized that the water content of peat may range from 200 to 2000% which is quite different from that for clay and silt deposits which rarely exceed 200%. Water content of fibrous peat generally is very high. It is because fibrous peat holds a considerable amount of water as its organic coarse particles are generally very loose and the organic particles itself are hollow and largely full of water (Rahman and Chan, 2014). In Parit Nipah Johor, the water content ranges from 330 to 650% (Azhar et al., 2016, Saedon and Zainorabidin 2012, Johari et al., 2016, Zainorabidin and Mohamad 2015; Yusoff et al., 2015).

Nurhamidah et al., (2011) reported that the tropical peat in tidal swamplands areas (Peninsular and East Malaysia) is identified with land subsidence on the peat layers. The Peninsular Malaysia area subsidence rate was found to be 2cm until
REFERENCES


Munro, R. (2004). Dealing with bearing capacity problems on low volume roads constructed on peat. The Highland Council, Environmental and Community Service, HQ, Glenurquhart Road, Interness IV3 5NX Scotland


