COMPRESSIBILTY CHARACTERISTICS OF FIBROUS PEAT SOIL

YULINDASARI

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To my beloved Father (Sutedjo), to my beloved mother (Rohyati), to my beloved brother (Andi Kurniawan, SE.), and to my beloved sister (Melya Kurniati, SE.). There's nothing in life that makes me happier than loving all of you.

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ABSTRACT

Peat has been identified as one of major groups of soils found in Malaysia. Peat deposit covers large area of West Johore especially Pontian, Batu Pahat, and Muar. Despite of this fact, not much research has been focused on the compression behavior of peat. This study is focused on the compressibility characteristics of fibrous peat based on time-compression curves derived from consolidation tests. The peat samples were collected from Kampung Bahru, Pontian, West Johore by block sampling method. The laboratory testing program included the standard laboratory testing for identification and classification purposes, i.e., Scanning Electron Micrograph (SEM), shear box test, constant head permeability test, Oedometer tests, and large strain consolidation test using Rowe cell. The results of the study show that the peat soil can be classified as fibrous peat with low to medium degree of decomposition (H_4 in von Post scale) and of very high organic content (97 %) and fiber content (90 %). The natural water content of the peat is 608 % which corresponds to initial void ratio of about 9. The undrained shear strength of peat is 10.10 kPa, with sensitivity of 5.64. The initial permeability is high, but it decreases significantly with applied pressures. The fibrous peat has a high compressibility with significant secondary compression stage, which is not constant with the logarithmic of time. Eventhough the duration of the primary consolidation was short, but the settlement was high. This is due to high initial void ratio. Besides, the magnitude of the secondary compression of fibrous peat is also significant with respect to the design life of a structure. The comparison between the results of the consolidation test using Rowe and Oedometer cells show that the use of Rowe cell for the evaluation of the consolidation characteristics of soil exhibiting secondary compression is advantageous because it enables the observation of the large deformation. The compression index (c_c) obtained from consolidation test on Rowe cell was 3.128, while the coefficient of secondary compression (c_α) range from 0.102 to 0.304. The settlement analysis performed for the hypothetical case of an embankment on peat deposit showed that the compression of fibrous peat deposit can be estimated based on the time-compression and the time-excess pore water pressure curves.

ABSTRAK

Tanah gambut dikenalpasti sebagai salah satu kumpulan utama tanah di Malaysia. Kawasan tanah gambut terdapat di Johor bahagian barat terutamanya Pontian, Batu Pahat, dan Muar. Walaupun demikian, tidak banyak penyelidikan tertumpu pada kelakuan pemampatan tanah gambut. Kajian ini tertumpu pada analisis sifat kebolehmampatan tanah gambut berdasarkan lengkung masa-pemampatan yang diperoleh daripada ujian pengukuhan. Sampel tanah gambut dari Kampung Bahru, Pontian, Johor barat dengan kaedah pensampelan blok. Program ujian makmal termasuk ujian piawaian makmal digunakan bagi tujuan mengenalpasti dan pengkelasan, iaitu mikrograf elektron imbasan (SEM), ujian kotak ricih, ujian kebolehtelapan turus malar, ujian pengukuhan Oedometer, dan ujian terikan tinggi menggunakan sel Rowe. Keputusan kajian menunjukkan bahawa tanah gambut boleh dikelaskan sebagai gambut gentian dengan darjah penguraian rendah ke sederhana (H_4 pada skala von Post) dan kandungan organik (97 %) dan kandungan gentian (90 %) yang tinggi. Kandungan lembapan asli bagi tanah gambut tersebut adalah 608 % dengan nisbah lompang mula 9. Kekuatan ricih tak bersalir gambut adalah 10.10 kPa dengan kepekaan 5.64. Kebolehtelapan mula adalah tinggi, tetapi nilainya berkurangan dengan tekanan. Gambut gentian mempunyai kebolehmampatan yang tinggi pada peringkat mampatan sekunder dan tidak malar dengan logaritma masa. Walaupun, tempoh pengukuhan utama adalah pendek tetapi enapan adalah tinggi. Ini disebabkan nisbah lompang mula yang tinggi. Selain itu, magnitud mampatan kedua bagi gambut gentian adalah penting juga untuk hayat rekabentuk sesuatu struktur. Perbandingan antara keputusan ujian pengukuhan sel Rowe dan sel Oedometer menunjukkan penggunaan sel Rowe untuk penaksiran sifat pengukuhan pada mampatan punya kelebihan kerana ia boleh meninjau ubah bentuk yang besar. Indeks mampatan (c_c) yang diperoleh dari ujian pengukuhan pada sel Rowe ialah 3.128, manakala julat mampatan sekunder (c_α) ialah 0.102 hingga 0.304. Analisis enapan yang dilakukan untuk kes hipotesis benteng di kawasan tanah gambut menunjukkan bahawa kebolehmampatan gambut gentian dapat dianggar berdasarkan kepada lengkung masa-pemampatan dan lengkung masa-tekanan air liang lebihan.

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A	-	Area of sample
a	-	Primary compressibility (based on Rheological model)
AC	-	Ash content
a_v		Coefficient of axial compressibility, Coefficient of volume compressibility
B	-	Pore pressure parameter
b	-	Coefficient of secondary compressibility (based on Rheological model)
c'	-	Effective cohesion
c_u	-	Undrained shear strength
c_c	-	Compression index
c_r	-	Recompression index
c_v	-	Coefficient of rate of consolidation
c_{vo}	-	Coefficient of rate of consolidation
c_α	-	Rate of secondary compression; Slope, Coefficient of secondary compression
$c_{\alpha 1}$	-	Coefficient of secondary compression
$c_{\alpha 2}$	-	Coefficient of tertiary compression
D	-	Diameter of sample
D_o	-	Initial reading; Deformation
D_{100}	-	Deformation corresponds to U = 100 %
d_z	-	Elemental layer of thickness at depth z
e	-	Void ratio

e_o	-	Initial void ratio
e_{op}	-	Void ratio at the beginning of secondary compression
e_c	-	Corrected void ratio
e_m	-	Measured void ratio
e_1	-	Void ratio of the compressible soil layer corresponding to compression δ_1 at time t_1
e_2	-	Void ratio of the compressible soil layer corresponding to compression δ_2 at time t_2
FC	-	Fiber content
G_s	-	Specific gravity
H	-	Thickness of consolidation soil layers; Initial thickness
H_d	-	Length of drainage path for a particular pressure increment
h	-	Height from the top of the sample to the level of water in the header tank; Head loss due to the height of water in the burette
i	-	Hydraulic gradient
k	-	Coefficient of permeability
k_v	-	Vertical coefficient of permeability
k_{vo}	-	Vertical coefficient of permeability
k_h	-	Horizontal coefficient of permeability
L	-	Longest drainage path in consolidating soil layer; equal to half of H with top and bottom drainage; and equal to H with top drainage only
LIR	-	Load increment ratio
m	-	Secondary compression factor
m_v	-	Coefficient of volume compressibility
OC	-	Organic content
pH		Acidity
p'	-	Consolidation pressure

p_o	-	Initial pressure; Seating pressure
p_1	-	Inlet pressure
p_2	-	Outlet pressure
Q	-	Cumulative flow
q	-	Rate of flow
q_v	-	Rate of vertical flow
q_h	-	Rate of horizontal flow
r	-	Radius of sample
S_t	-	Sensitivity
S_c	-	Consolidation settlement
S_s	-	Secondary compression
T	-	Time
T_v	-	Vertical theoretical time factor, Time factor
T_c, T_{ro}, T_r	-	Theoretical time factors
T_{50}, T_{90}	-	Theoretical time factors
$t^{0.5}$, $t^{0.465}$	-	Time function
t	-	Time
t_o	-	Beginning of secondary compression
t_p	-	Beginning of secondary compression; End of primary consolidation; Time for primary consolidation; Time of the completion of primary consolidation
t_s	-	Time of secondary compression; End of secondary compression
t_f	-	Time for the secondary compression settlement
t_{100}	-	End of primary consolidation; Time of the completion of primary consolidation
U_h	-	Average degree of consolidation due to horizontal drainage

U_v	-	Average degree of consolidation due to vertical drainage
u	-	Excess pore water pressure at any point and any time
u_o	-	Initial excess pore water pressure
u_e	-	Excess pore water pressure
u_{avg}	-	Average degree of consolidation
μ_e	-	Excess pore water pressure
ω_o; ω	-	Natural water content
x	-	Difference in the dial reading
Δe	-	Change of void ratio from t_p to t_f
ΔH	-	Consolidation settlement
ΔV	-	Change in volume
Δp	-	Pressure difference
$\Delta\sigma'$	-	Additional stress, The change in the effective in e-p' curve
β	-	Degree of compression
ε_i	-	Instantaneous strain
ε_p	-	Primary strain
ε_s	-	Secondary strain; Measured compression strain during sampling
ε_t	-	Tertiary strain
γ	-	Unit weight
γ_w	-	Unit weight of water
σ	-	Effective stress
σ'_v	-	Effective vertical stress
σ'_o	-	Existing overburden pressure
σ'_p	-	In-situ effective stress
σ_c'	-	Pre-consolidation pressure

τ'_f	-	Shear strength
ϕ'	-	Effective internal friction, Friction angle
δ	-	Total compression
δ_p	-	Primary consolidation settlement
δ_s	-	Secondary compression
Z	-	Geometry factor, Depth
†	-	Drain ratio 1/20

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CHAPTER 1

INTRODUCTION

1.1 Background

Peat has been identified as one of the major groups of soils found in Malaysia. Three million hectares or 8 % of the area is covered with peat (Huat, 2004). Some 6300 Hectares of the peat-land is found in Pontian, Batu Pahat and Muar, West Johore area. On the west coast of Malaysian peninsular, the peat deposits are formed in depressions consisting predominantly of marine clay deposits or a mixture of marine and river deposits especially in areas along river courses. There are two types of peat deposit, the shallow deposit usually less than 3 m thick while the thickness of deep peat deposit in Malaysia exceeds 5 m. The underlying materials is usually consists of marine clay (Muttalib et al., 1991).

Recently, the utilization of peat-land in Malaysia is quite low although construction on marginal land such as peat has become increasingly necessary for economic reasons. Engineers are reluctant to construct on peat because of difficulty to access the site and other problems related to unique characteristics of peat. Therefore, not much research has been focused on the behavior of peat and the development of soil improvement method for construction on peat soil area.

Replacing the peat with good quality soil is still a common practice when construction has to take place 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 (Lea and Brawer, 1963; Berry, 1983; Hansbo, 1991). Alternative construction and stabilization methods such as surface reinforcement, preloading, chemical stabilization, sand or stone column, pre-fabricated vertical drains, and the use of piles were discussed in literatures (Noto, 1991; Hartlen and Wolsky, 1996; Huat, 2004, and others). The selection of the most appropriate method should be based on the examination of the index and engineering characteristics of the soil. The knowledge on the shear strength and 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.

There are two types of peat: amorphous peat and fibrous peat (ASTM D4427). The compressibility behavior of the amorphous peat is known to be similar with clay soil which can be evaluated based on Terzaghi's theory of consolidation. Fibrous peat is peat with high organic and fiber content with low degree of humification. The behavior of fibrous peat is different from mineral soil because of different phase properties and microstructure (Edil, 2003), thus Terzaghi's theory of consolidation cannot be applied to predict the compression behavior of fibrous peat.

The compression behavior of fibrous peat consists of two phases i.e.: primary consolidation and secondary compression. The primary consolidation of fibrous peat is much larger than that of other soils due to high initial water content, while the secondary compression occurs due to not only compression of solid particles, but also the plastic yielding (buckling, bending, and squeezing) of the particles (Samson and La Rochelle, 1972). The magnitude of secondary compression takes more significant part of the compression of peat and plays an important role in determining the total settlement of the peat because the secondary compression occurs during the design life of a structure after the rapid primary consolidation. Tertiary compression was reported by several researchers (e.g. Candler and Chartres, 1988; Fox et al., 1992; Mitchell, 1993), but other researchers (e.g. Edil and Dhowian, 1979; Hansbo, 1991; Fox and Edil, 1994) argued that this part of compression can be neglected because it generally started after the design life of structure.

Fiber orientation is identified as a dominant factor in the structure of fibrous peat. The application of consolidation pressure may induce a rearrangement of fiber orientation and drastically reduces the void, causing a significant reduction in the vertical permeability. Moreover, fiber content appears to be a major compositional factor in determining the way in which peat soils behave (Dhowian and Edil, 1980). The higher the fiber content, the more the peat will differ from an inorganic soil in its behavior. In order to develop a visual appreciation of the fiber content and orientation, the microstructure of the peat was examined under a Scanning Electron Microscope (SEM).

Many researchers (Berry and Poskitt, 1972; Ajlouni, 2000; Robinson, 2003) have examined fibrous peat from different parts of the world and their findings are quite different from one and another due to different content of peat soils. The properties of peat soils such as natural water content, acidity, degree of humification, fiber content, shear strength, and compressibility is affected by the formation of peat deposit. This indicates that in term of content, fibrous peat is different from one location to another location and detailed soil investigations need to be conducted for fibrous peat at a particular site where a building is intended to be constructed. The difference becomes particularly apparent especially under low vertical stresses or shallow depth. Thus assessment on the response of peat deposit to loading should be made before any construction has to take place at a particular site.

Most of the methods to predict compressibility characteristics of soil are developed based on the results of laboratory consolidation test. Several test methods have been used to study the compressibility of different type of soil including peat. The oldest and the most popular one is the conventional Oedometer test. This test is still used as a standard consolidation test method in Malaysia as well as in many parts of the world. More advanced testing methods have also been developed such as for example the Rowe cell or large strain consolidometer, and constant rate of strain (CRS) test. Among these testing methods, Rowe cell has the capability of testing large diameter sample to provide more reliable data for settlement analysis (Head, 1986).

1.2 Problem Statement

The compressibility behavior of fibrous peat is different from that of clay soil. The behavior is controlled by several factors including the initial water content, fiber arrangement, and fiber content. The condition in which the fibrous peat is deposited is also an important factor to be considered.

The large compressibility of peat results in a large deformations and strains. Accordingly, equipment capable of measuring large strain consolidometer is needed to study the compressibility characteristics of peat. Several consolidation parameters of the peat under study will be determined. The results are useful for identification of the compressibility characteristics and predicting the compression behavior of fibrous peat.

1.3 Objectives

Based on the uniqueness of the properties of fibrous peat and the importance of compressibility of the peat in the evaluation of its response to loading, the following objectives were set forth:

1. To identify the type and engineering properties of peat found in Kampung Bahru, Pontian, West Johore.
2. To study the compressibility characteristics of the fibrous peat based on the results of consolidation test using large strain consolidometer (Rowe Cell).
3. To investigate the suitable method for predicting compression behavior of fibrous peat and estimating settlement based on the time-compression curve derived from the test.

1.4 Scopes

The study focuses on the compressibility characteristics of peat soil found in Kampung Bahru, Pontian, West Johore. Therefore, the interpretation of the results of the study was limited as indicated in the followings:

1. Peat soil found in Kampung Bahru, Pontian, West Johore.
2. Samples were obtained using block sampling method (procedure outlined in Appendix A).
3. Identification of index properties of soil includes: water content, specific gravity, sieve analysis, and acidity.
4. Classification of peat was made based on degree of humification (von Post) as well as the fiber and organic content.
5. Evaluation of shear strength of the peat was made by vane shear (field) and shear box tests (laboratory).
6. Evaluation of permeability based on constant head permeability test.
7. The use of the standard consolidation test (Oedometer) data to determine the range of pressure and estimate the length of primary consolidation to be applied in large strain consolidation test (Rowe Cell).
8. Evaluation of compressibility characteristics was made based on the results of large strain consolidation test (Rowe Cell)
9. Comparison of the data obtained from large strain consolidation test with those obtained from the standard consolidation test.
10. Evaluation of the effect of fabric on the compressibility characteristics based on Scanning Electron Micrograph (SEM) and consolidation test done with horizontal drainage.
11. Evaluation of the settlement was made on a hypothetical problem.

1.5 Significance of Study

This research will enrich the knowledge on the characteristics of peat soil and the results will be used in the development of suitable soil improvement for fibrous peat in Kampung Bahru, Pontian, West Johore as foundation as well as construction material.

1.6 Thesis Structure

The thesis is composed of six chapters. Chapter 1 presents general information regarding background, problem statement, objectives, scope, and significance of the study, and thesis structure. Chapter 2 provides the background of the study on different topics related to the research. This chapter outlines information on the general characteristics of fibrous peat, the theory of consolidation, the compressibility of fibrous peat, and the theories and models developed by researchers for the study of the compressibility of peat. Chapter 2 also covers review on the standard consolidation test as well as the large strain consolidation test on Rowe cell.

Chapter 3 provides the overall experimental program including laboratory tests and data analysis. The experimental program includes sampling of peat and laboratory soil tests performed to classify the soil and to determine the engineering properties of peats. This chapter also discuss the detail set up and procedures of large strain consolidation test on Rowe cell and analysis of the data obtained from the test.

Chapter 4 presents general characteristics of the peat derived from the results of preliminary test. These include soil identification, soil classification, fiber content, shear strength, initial permeability, and compressibility data obtained from the standard consolidation test on Oedometer cell.

Chapter 5 presents the results obtained from large strain consolidation test on Rowe cell. Analysis of the test data for determining the compressibility parameters are presented and discussed in detail in this chapter. Comparisons of the results of large strain consolidation test with data obtained from the standard consolidation test on Oedometer cell are also presented. Furthermore, the compression behavior obtained from Rowe consolidation test were compared to published data in terms of time-compression curve, consolidation curve, and the range of compressibility parameters. Effect of fiber on the compressibility of the soil is also highlighted in this chapter. Finally, the applications of consolidation parameters from large strain consolidation test for settlement analysis based on hypothetical problem are also discussed in Chapter 5.

Chapter 6 presents the summary and conclusions of major findings of this research and recommendation for future work on the topic related to the present study.

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