UNIVERSITI PUTRA MALAYSIA

LIGHTWEIGHT BUOYANT FOUNDATION ON PEAT SOIL USING BAMBOO CULMS AND PLASTIC BAGS

AMINU IBRAHIM

FK 2018 22

LIGHTWEIGHT BUOYANT FOUNDATION ON PEAT SOIL USING BAMBOO CULMS AND PLASTIC BAGS

By

AMINU IBRAHIM

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

September 2017

DEDICATION

To the memory of my late Parent ***Aisha and Ibrahim,*** my dear Wife, ***Sa'adatu***, my children, ***Khadijah, Fadimatu, Maryam and Aisha;*** and my dear and reliable friend ***Alhaji Zubairu Lawal (Dallatun Tudunwada Gusau, Zamfara State, Nigeria).***

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

LIGHTWEIGHT BUOYANT FOUNDATION ON PEAT SOIL USING BAMBOO CULMS AND PLASTIC BAGS

By

AMINU IBRAHIM

September 2017

Chairman : Professor Bujang Bin Kim Huat, PhD
Faculty : Engineering

Foundation construction on peat is extremely difficult due to its poor engineering properties. Construction methods on peat include excavation, displacement and replacement, and are uneconomical when its thickness is high. Soil improvement techniques successfully applied on mineral soils are inapplicable on peat due to inadequate stiffness and difficulty in using heavy equipment. Peat is neither purely water nor purely soil, but possesses very high moisture content that could generate buoyancy effect. The use of bamboo and geotextile for embankment construction on soft soil being proclaimed to exhibit buoyancy effect is merely understood as separation technique, as it does not obey the Archimedes' principle. More so, they are usually for road embankments and not for buildings structures. Buoyancy effect has yet to be explored for construction on peat, be it embankment or otherwise, and therefore, needs to be investigated. Little study has been done on the use of lightweight and waste materials as foundation materials on peat due to its very low shear strength.

In this research, a lightweight buoyant foundation model using bamboo culms and plastic bags has been developed for lightweight building construction on peat. Effects that will enhance its performance have been investigated through physical and numerical modelling, including the moisture content and fibre content of peat; volume of bamboo frame and bamboo-plastic bags frame models. Foundation capacity improves by 25 % with increase in moisture content of sapric peat from 627 % to 1,185 % and by 37.5 % with increase to 1,634 %. The capacity improves on hemic peat by 43 %, with increase from 634 % to 1,213 % and by 100 % with increase to 1,698 %. On fibric peat the capacity improves by 61 %, with increase from 715 % to 1,221 % and by 117 % with increase to 1,759 %. Increase in fibre content of peat from 17 % to 54 % improves the capacity by 900 %, and by over 2000 % with increase to 87 %.

The capacity increased by 38 % with increase in volume of bamboo frame from $1.125e^{-3}$ m^3 to $1.325e^{-3}$ m^3, and by 48 % with increase to $1.625e^{-3}$ m^3. Plastic bags inclusion in bamboo-plastic bags frame increases the capacity by 66 %, with volume increases from $1.125e^{-3}$ m^3 to $1.764e^{-3}$ m^3, by 58 % with increases from $1.325e^{-3}$ m^3 to $2.646e^{-3}$ m^3 and by 57 % with increase from $1.625e^{-3}$ m^3 to $4,040e^{-3}$ m^3. The most effective peat is fibric, followed by hemic and sapric. Physical and numerical modelling results were compared using the ABAQUS CAE 6.11 Finite Element Method (FEM) analysis which conforms to each other. A design procedure and equations has been developed as a guide for the construction of the foundation model with an illustrative example. Use of bamboo and plastic bags for foundation construction will limit construction problems, mitigate the menace of plastic bag waste and is a green technology research in geotechnical engineering.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

TANAH GAMBUT ASAS RINGAN MENGGUNAKAN BULUH CULMS DAN BEG PLASTIK

Oleh

AMINU IBRAHIM

September 2017

Pengerusi : Profesor Bujang Bin Kim Huat, PhD
Fakulti : Kejuruteraan

Pembinaan asas pada Tanah Gambut adalah amat sukar kerana sifat-sifat kejuruteraan yang miskin. Kaedah pembinaan pada Tanah Gambut termasuk pengorekan, anjakan dan penggantian, dan adalah tidak ekonomi apabila ketebalan yang tinggi. Teknik pembaikan tanah yang berjaya menggunakan mineral tanah akan diterapkan pada Tanah Gambut disebabkan oleh kekakuan tidak mencukupi dan kesukaran dalam menggunakan jentera berat. Tanah Gambut adalah air semata-mata mahupun tanah semata-mata, tetapi memiliki kandungan lembapan yang sangat tinggi yang boleh menghasilkan kesan keapungan. Penggunaan buluh dan Geotekstil Tenun bagi pembinaan tambak keatas tanah lembut yang dicanangkan untuk mempamerkan kesan keapungan hanya difahami sebagai teknik pemisahan, kerana ia tidak mematuhi prinsip Archimedes'. Lebih-lebih lagi, mereka biasanya adalah untuk jalan Cardon dan bukannya untuk struktur bangunan. Kesan keapungan masih belum diterokai untuk pembinaan pada Tanah gambut, samada tambakan atau sebaliknya, dan oleh itu, perlu disiasat. Sedikit kajian telah dilakukan dengan penggunaan bahan-bahan ringan dan sisa sebagai bahan-bahan asas pada gambut disebabkan oleh kekuatan ricih yang sangat rendah.

Dalam kajian ini, model asas melambung ringan yang menggunakan buluh culms dan beg plastik telah dibangunkan untuk pembinaan bangunan pada Tanah Gambut. Kesan yang seterusnya akan meningkatkan prestasinya telah dikaji melalui permodelan numerik dan fizikal, termasuk kandungan lembapan dan kandungan serat gambut; bilangan buluh bingkai dan buluh-plastik beg rangka model. Cerucuk meningkatkan sebanyak 25% dengan peningkatan kandungan lembapan tanah gambut sapric daripada 627% kepada 1,185% dan 37.5% peningkatan kepada 1,634%. Kapasiti memperbaiki pada tanah gambut hemic dengan 43%, dengan peningkatan daripada 634% 1,213% dan 100% dengan peningkatan % 1,698. Pada Tanah Gambut fibric

keupayaan meningkatkan sebanyak 61%, peningkatan dari 715% % 1,221 dan 117% peningkatan kepada 1,759%. Peningkatan kandungan gentian gambut dari 17% kepada 54% meningkatkan kapasiti sebanyak 900%, dan lebih 2000% dengan peningkatan kepada 87%.

Kapasiti meningkat sebanyak 38% dengan peningkatan dalam bilangan kerangka buluh dari 1.125e-^{3} m^{3} hingga 1.325e-^{3} m^{3}, dan 48% dengan peningkatan kepada 1.625e-^{3} m^{3}. Kemasukkan beg plastik ke dalam buluh-plastik beg bingkai meningkatkan kapasiti sebanyak 66%, dengan jumlah kenaikan dari 1.125e-^{3} m^{3} hingga 1.764e-^{3} m^{3}, sebanyak 58% dengan kenaikan daripada 1.325e-^{3} m^{3} hingga 2.646e-^{3} m^{3} dan sebanyak 57% dengan kenaikan daripada 1.625e-^{3} m^{3} hingga 4, 040e-^{3} m^{3}. Tanah Gambut yang paling berkesan adalah fibric, diikuti dengan hemic dan sapric. Keputusan pemodelan fizikal dan berangka dibandingkan menggunakan analisis ABAQUS CAE 6.11. Kaedah (FEM) yang mematuhi antara satu sama lain. Prosedur rekabentuk dan persamaan yang telah dibangunkan sebagai panduan untuk pembangunan model asas dengan contoh ilustrasi. Penggunaan buluh dan beg plastik untuk pembinaan asas akan menghadkan masalah pembinaan, mengurangkan ancaman bagi pembaziran beg plastik sampah dan penyelidikan teknologi hijau dalam Geoteknik Kejuruteraan.

ACKNOWLEDGEMENTS

All praises and thanks are due to Allah the Lord of the universe. May peace and blessings of Allah be upon His noble Prophet and Messenger Muhammad (Salla-Allahu Alaihi Wasallam). I offer my profound gratitude to Allah (Subhaanahu Wa-Ta'Aalah), who made this entire PhD research journey a reality and success.

I would like to express my most sincere appreciation to my supervisory committee members, Professor Bujang Bin Kim Huat, Dr. Haslinda Nahazanan, Associate Professor Ir. Dr. Low Kaw Sai and my former supervisor Dr. Afshin Asadi, for their kind support, guidance and objective criticism throughout the study period.

The financial support from Putra Initiative Graduate Grant (GP-IPS) Project ID: GP-IPS/2015/9452200 is highly acknowledged as well as the Tertiary Education Trust Fund (TETFUND) of Nigeria. Also acknowledged is the Faculty of Engineering Universiti Putra Malaysia, particularly Mr. Razali, Mr. Sukheri, Mr. Haffis and Mr. Mustaqim for their technical support on the use of school items and laboratory facilities. Sincere thanks are also due to Professor Dr. Oliver Reul from the University of Kassel, Germany and Associate Professor Dr. Brendan O'Kelly from University of Dublin, Trinity College, Ireland; for their kind contributions towards the success of my research activities.

My sincere regards and appreciation goes to Alh. Zubairu Lawal "Dallatun T/wada Gusau" for his moral and financial support in the overall success of this research activity. I also appreciate my colleagues such as Dr. Vivi Anggraini, Dr. Aliyu Isah Take Tsaba, Dr. Suleiman Lawal Gambo, Dr. Sani Muhammad Bida, Dr. Nafi"u Lawal and host of others for their company, assistance and encouragement throughout the conduct of this research.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Bujang Bin Kim Huat, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Haslinda Nahazanan, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Low Kaw Sai, PhD
Associate Professor
Faculty of Engineering
Universiti Tunku Abdul-Rahman
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature: ______________________________
Name of Chairman of Supervisory Committee: Professor Dr. Bujang Bin Kim Huat

Signature: ______________________________
Name of Member of Supervisory Committee: Dr. Haslinda Nahazanan,

Signature: ______________________________
Name of Member of Supervisory Committee: Associate Professor Dr. Low Kaw Sai

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

EPS	Expanded Polystyrene
FEM	Finite Element Method
ASTM	American Society For Testing and Materials
BS	British Standard
LVDT	Linear Variable Displacement Transducer
M1	Bamboo frame model 1 stage I test
M2	Bamboo frame model 2 stage I test
M3	Bamboo frame model 3 stage I test
M4	Bamboo-plastic bag frame model stage I test
M5	Bamboo-plastic bag frame model stage I test
M6	Bamboo-plastic bag frame model stage I test
M7	Bamboo frame model 7 stage II test
M8	Bamboo frame model 8 stage II test
M9	Bamboo frame model 9 stage II test
M10	Bamboo-plastic bag frame model stage II test
M11	Bamboo-plastic bag frame model stage II test
M12	Bamboo-plastic bag frame model stage II test
Sapric peat	S1, S2 and S3
Hemic peat	H1, H2 and H3
Fibric peat	F1, F2 and F3.
GW	Ground Water
W	Weight of object
m	Mass of the object;
g	Acceleration due to gravity;

S_u,	Undrained shear strength
c	Cohesion
ϕ	Friction angle
γ_b	Bulk densities of peats
ρ_{object}	Density of object
ρ	Bulk density
ρ_d	Dry density
$F_{buoyant}$	Buoyant force
ρ_{fluid}	Density of fluid
γ	Unit weight
$V_{fluid\ displacedb}$	Volume of fluid displaced
V_{object}	Volume of object submerged
M	Foundation model
ρ_M	Density of the foundation model
$V_{M\ submerged}$	Volume of the foundation model submerged
ρ_{peat}	Density of peat;
$V_{peat\ displaced}$	Volume of peat displaced
W_i	Total weight of the foundation model including the applied load
W_M	Weight of the foundation material alone
Q_a	Applied load on the foundation system
V_c	Volume of composite foundation
V_{bb}	Volume of bamboo
V_{pb}	Volume of plastic bags
M_{bb}	Mass of bamboo
ρ_{bb}	Density of bamboo

M_{pb}	Mass of plastic bags
ρ_{pb}	Density of plastic bags
V_{pb}	Volume of plastic bags

CHAPTER 1

INTRODUCTION

1.1 Introduction

Peat has been described as an accumulation of disintegrated plant vestiges which have been under conditions of incomplete aeration due to lack of adequate oxygen caused by high water content and represents the extreme form of soft soil with water level very close to the ground surface (Huat, Prasad, Asadi, & Kazemian, 2014). It has also been classified as a soil having organic matter of more than 75% (ASTM D, 2007). It usually accumulates in areas with a water-saturated environment and excess rainfall, with poorly drained or undrained and waterlogged soil conditions that favour the growth of some type of vegetation and help preserve the plant remains (Huat et al., 2014).

Peat is found in all continents except in deserts and the arctic regions (Deboucha, Hashim, & Alwi, 2008). Canada has the largest peat area followed by former USSR with 150 million hectares each (Huat et al., 2014; Nichol, 1998). Its deposits exist in 42 states of the United States of America where Alaska, Minnesota, Wisconsin, Florida, and New York are among the ones with large areas (Mesri & Ajlouni, 2007). In Malaysia, it covers about 3 million hectares (8 %) of the country's land area. The depth of peat is generally shallower near the coast and increases inland, exceeding more than 30 m (Huat et al., 2014). Peat has a very low bearing capacity, high compressibility and settlement for a long period of time; which are directly related to some of its poor engineering properties. Allowable bearing pressure for peat usually does not exceed 20 kPa, and one of its most important properties is the moisture content which is up to over 2000 % (Huat et al., 2014). The undrained shear strength S_u, of peat is very low, with cohesion c, values between the range of 6 and 17 kPa and friction angle ϕ, values between 3 and 25˚. The shear strength of peat soil falls within the range of 3-17 kPa (Huat et al., 2014). The bulk densities of peats γ_b, are within the range of 0.8-1.2 Mg/m^3 as compared with those of mineral soils which range between 1.8-2 Mg/m^3 (Huat et al., 2014).

The low bearing capacity in peat is due to the low shear strength it possesses. Thus, c and ϕ cannot contribute to bearing capacity gains in peat. The low saturated density of peat coupled with its ground water very close to the ground surface makes it to portray a very low effective stress unless artificially loaded, and it tends to be overconsolidated due to the seasonal ground water fluctuation even if it is not subjected to artificial stress (Hayashi, Yamazoe, Mitachi, Tanaka, & Nishimoto, 2012).

Various construction techniques have been carried out to support foundation and embankment construction on peat without risking bearing failures but settlement of these embankments remains excessively large and continues for many years (Huat et al., 2014). Besides settlement, stability problems during construction such as localized bearing failures and slip failures need to be considered (Duraisamy, Huat, & Aziz, 2007). The applications of these methods are constrained by technical feasibility, construction cost, space and time constraints; and sometimes client's preferences (Gan & Tan, 2003).

Avoidance is the easiest method of construction on peat. But due to lack of adequate suitable land area for infrastructure development, it becomes no longer an alternative (Huat et al., 2014; Munro, 2004; Munro, Evans, & Saarenketo, 2007). The conventional construction techniques on peat include excavation, replacement and displacement; or alternatively convey the loads to a firmer bearing layer by piles or simply piled raft foundation (Huat et al., 2014; Munro, 2004; Munro et al., 2007). In situations where the depth of peat is very high (for example in Malaysia is over 20 m), this method is uneconomical (Huat et al., 2014).

Another alternative is to increase its properties through stabilization where a laboratory experiment portrays that cement columns with high cement ratio installed in peat could reduce compressibility and settlement of peat (Kazemian, Asadi, Huat, Prasad, & Rahim, 2010). Another aspect of peat soil stabilization is the use of optimum dose of cement and silica fume for stabilizing the upper layer of in-situ peat soil to increase the strength of sub-base for pavement construction (Kalantari, Prasad, & Huat, 2011). One novel investigation is the addition of salt grains to fibrous peat in order to accelerate its rate of primary consolidation and reduce its creep rate under similar loading conditions, by expelling larger volumes of micropore water during primary consolidation (Lin Zhang & O'Kelly, 2015). Limitation to this kind of peat improvement is that they are mostly restricted to the laboratory tests, and no significant investigation is conducted based on the physical stress-strain behaviour of the peat under applied stress.

A number of reports confirm that saturated peat has high potential to flow (Hungr & Evans, 1985; Warburton, Holden, & Mills, 2004). It exhibits a slow to very rapid flow-like movement due to the high pore pressure it contains (Hungr & Evans, 1985). This indicates that peat behaves as quasi-solid and lies along the boundary between a solid and a liquid. Therefore, hypothetically, the high water content in peat and its quasi-solid properties provide potential for buoyancy generation. This potential has yet to be explored.

Archimedes' principle indicates that the upward buoyant force that is exerted on a body immersed in a fluid is equal to the weight of the fluid that the body displaces and acts in the upward direction at the centre of mass of the displaced fluid. As c and ϕ of peat are low and cannot provide the necessary bearing capacity, the idea of using lightweight materials with lower density than the peat bulk density may suggest a novel conceptual model for foundation system with less bulk earthworks using the Archimedes' principle of buoyancy. The upward force exerted by peat that opposes the weight of an immersed object (e.g. foundation) may support the loads applied on the peat.

Bamboo is fast growing specie which attains its full length in 2 to 3 months and its maturity in 2 to 3 years (Gnanaharan, Janseen, & Arce, 1994). It is available in all the continents of the world except Europe (Salleh, 1996) and known to possess a good strength to weight ratio (Ali & Abdullah, 1984). Malaysia has about 70 different species of bamboo. Stronger species are found in the northern states while a specie known as 'Bambusa vulgaris' is found in all states (Ali & Abdullah, 1984). Bamboo has been used as a sustainable foundation construction material for decades and without much difficulty (Huat et al., 2014; Munro, 2004; Munro et al., 2007; Rahardjo, 2005). It is durable when fully submerged under water (Kamali & Hashim, 2010; Rahardjo, 2005).

Another novel construction technique on soft ground is the use of bamboo-geotextile composite base tagged as 'Geobamtile' that provide a sufficiently wide area of stress distribution using the extra ordinary potentials of buoyancy as well as bending-without-failure ability of the bamboo, in order to decrease the intensity of the applied vertical stress on soft ground hitherto which could have resulted in an abrupt subgrade failure under the minute area of the stress application (Sai & Heng, 2016). It is noteworthy that research and other similar researches on the use of bamboo with geotextile are solely for separation between the problem soil and the embankment, and not similar to the Archimedes' buoyancy effect where materials must be submerged in fluid.

Plastic bags contribute a lot of environmental havoc in the society and the alternative disposal techniques are still in their infancy. In the recent past, several legislative activities and campaigns have been carried out in different cities of the world to restrict the use of plastic shopping bags due to the menace developed thereof. From news published by the Free Malaysia Today (FMT) on December 21st, 2016, the Selangor state government of Malaysia restrained retailers in providing free single-use plastic bags to the customers effective from January, 2017, where the solace being enjoyed in its free usage is now replaced with a charge of 20 cent for each plastic bag required by customers (retrieved on 1/26/2017.9:45am). With the advent of converting waste to wealth nowadays, using plastic bags for foundation purposes in peat will not only help in mitigating the menace of environmental pollution caused thereby, but also will originate a novel research field in the geotechnical engineering.

Plastic bags are durable and better understood to degrade as a result of sunlight spectrum rather than bacterial decomposition as bacteria do not recognise its chemical compounds as feed materials (EarthTalk®, 2010; Kenneth, 2011). On estimate, they could breakdown within 10 to 100 years (EarthTalk®, 2010) or even up to 500 years (Kenneth, 2011) when exposed to ultra violet light, and if unexposed could stay indefinitely (Kenneth, 2011; Service, n. d.).

There have been extremely few efforts made in the recent past in coming up with a suitable foundation construction methods on peat. One of the few researches in that area is related to compensation effect through excavation and use of Expanded Polystyrene (EPS) for lightweight farm structure (Abdullah, Huat, Kamaruddin, Ali, & Duraisamy, 2007). In this method, a potential replacement technique for the conventional pile foundation on peat was proposed. One of its demerits is that it is meant for only lightweight and temporary agricultural farm structures, and the EPS is not cost effective (Abdullah et al., 2007).

Until now, however, there is no available research in the literature where the behaviour of a lightweight foundation has been fully characterized on peat, and waste materials have been used as foundation materials.

In this research, the behaviour of lightweight buoyant foundation made up of bamboo and plastic bags, through the Archimedes' buoyancy effect is studied. Different factors and effects such as the moisture content and fibre content of peat and volume of foundation materials used (bamboo and plastic bags) were fully examined. Furthermore, comparison was made between the physical modelling and Finite Element Method (FEM) results on the capacity of the foundation model, and lastly design example using charts and equation has been presented.

1.2 Problem statement

Peat occupies a significant space and is found everywhere in the world except in the desert and cold regions. It poses difficulties in construction activities due to its poor characteristic nature such as high moisture content, high compressibility, settlement for a long period and extremely low shear strength. It is well known to occupy a huge percentage of the land areas in Malaysia and Indonesia.

The lack of adequate suitable land for infrastructure development such as the industries, roads, residential and office accommodation; makes it mandatory to access such lands for different construction activities.

Most of the existing methods of construction on soft inorganic soil are not applicable on peat due to its handling difficulties such as the use of heavy equipment during construction.

Mineral soil stabilization techniques such as soil column, stone column, geopier, etc., have not been successfully utilized on peat due to the lack of adequate stiffness.

Bamboo and geotextile have been used successfully on soft soil like peat for embankment construction and are proclaimed to exhibit the buoyancy effect, but are merely used as separators between the soft soil and road embankments. These can easily be understood as a separation technique, being that it only involves few layers of bamboo and geotextile and not as a result of immersion of the duo in water (fluid) as described in the Archimedes' principle. These techniques are usually adopted for road embankments only while buildings structures are not included.

Therefore, a thorough research for understanding the Archimedes' buoyancy effect on soft soils like peat might pave way for a sustainable construction on peat, be it embankment or otherwise, due to the high moisture content that could generate this effect which has yet to be explored for construction purposes on peat. This research gap prompted the need for this research.

Furthermore, little study has been done on the use of lightweight waste materials as foundation materials in order to further harness the potential of buoyancy effect on peat. No study as well has been conducted which involves the different types of peat where its different properties have been fully dealt with. This also forms another research gap in the literature.

The use of simple materials such as bamboo and waste materials like plastic bags for foundation construction on peat will not only limit the construction problems therein, but will also mitigate the menace of plastic bag waste and a novel green technology research in geotechnical engineering.

1.3 Objectives of the research

The aim of this research is to develop a lightweight buoyant foundation model on peat using bamboo culms and plastic bags as foundation materials. Certain effects have been designed through physical and numerical modelling approach in order to investigate the capacity of the model to be suitable for lightweight building construction on peat as itemised in the following objectives:

1. To investigate the effect of moisture content of peat on the capacity of the foundation model using physical modelling approach.
2. To investigate the effect of fibre content of peat on the capacity of the foundation model using physical modelling approach.
3. To examine the influence of volume of bamboo and plastic bags used on the effectiveness of the foundation model using physical modelling approach.
4. To compare the results of physical modelling and finite element method (FEM) analysis on the behaviour of the model.
5. To develop a procedure and model equations as a guide for the design of the foundation model.

1.4 Significance of the research

The significance of this research is to explore more ways of construction on peat (with less bulk earthworks) other than the conventional methods through the buoyancy effect. This will further increase the current state of knowledge and practice with respect to construction on peat. More so, the use of bamboo and plastic bag wastes for foundation purposes will not only solve the impending problem of construction over peat, but will also develop a green technology research in geotechnical engineering that is environmentally friendly. It is also important that, the future direction of construction in peat will now be based on buoyancy effect rather than depending on shear strength of peat.

1.5 Thesis organization

The thesis has been organised into five chapters in the following sequence:

Chapter 1 provides the general information and introduction of the research topic, problem statement, objectives of the research, significance of the research as well as the thesis organisation.

Chapter 2 provides the general review of the literature on peat and organic soils under the auspices of distribution of peat, classification of peat and engineering properties of peat. It also provides information on bamboo regarding its basic characteristics, distribution, properties, durability and previous work on bamboo grillages. Information on plastic bags in terms of its effect in the environment, durability and some of the constructions undertaken using the material has also been provided herein. A review was also provided on the various construction methods over peat, as well as, floating foundation system, and their shortcomings. Lastly, the chapter provides the summary of the literature where the gap in knowledge was identified and thus, the importance of the study justified.

Chapter 3 provides information on the methodology designed to achieve the desired objectives of the research beginning with a flow chart portraying the plan and sequence of events in this study, the sampling location and methods of sampling adopted, in-situ and laboratory tests in order to determine some of the physical and engineering properties of the materials used in this research, buoyancy effect on peat, physical modelling on the behaviour of the foundation system, comparison between the physical modelling and finite element method (FEM) results, and lastly development of the design example and simple charts and equation for the system.

Chapter 4 presents the results and discussion on the entire work undertaken in this research according to the sequence of the objectives identified such as the results on the properties of the materials used, results on physical modelling stage I and stage II, the comparison between physical modelling and the finite element method (FEM) analysis results, and finally the results on the development of design procedure and model equations for the foundation model.

Chapter 5 was fully dedicated for the conclusions and recommendations for future work in this area of study.

REFERENCES

Abdullah, M., Huat, B., Kamaruddin, R., Ali, A., & Duraisamy, Y. (2007). Design and Performance of EPS Footing for Lightweight Farm Structure on Peat Soil. *American Journal of Applied Sciences, 4*(7), 484-490.

Al-Ani, H., Oh, E., Eslami-Andargoli, L., & Chai, G. (2013). Subsurface visualization of peat and soil by using GIS in Surfers Paradise, Southeast Queensland, Australia. *Electronic Journal of Geotechnical Engineering, 18*(1761), 1774.

Alexiew, D., Brokemper, D., & Lothspeich, S. (2005). Geotextile encased columns (GEC): load capacity, geotextile selection and pre-design graphs *Contemporary Issues in Foundation Engineering* (pp. 1-14).

Ali, A. A. A., & Abdullah, A. (1984). Development of basic mechanical tests for Malaysian bamboos: Pertanika.

Allgood, C., Weppler, L., Lien, B., & Fox, N. S. (2003). *Geopier® Intermediate Foundation Systems–Case Studies for Building Foundations over Soft Organic Soils and Peat*. Paper presented at the Proceeding of the Nottingham Problematic Soils Conference.

Ambily, A., & Gandhi, S. R. (2007). Behavior of stone columns based on experimental and FEM analysis. *Journal of geotechnical and geoenvironmental engineering, 133*(4), 405-415.

ASTM D. (2007). 4427-92,“. *Standard Classification of Peat Samples by Laboratory Testing”, Book of ASTM Standards, Philadelphia*.

Bajad, S., & Sahu, R. (2008). *An experimental study on the behavior of vertically loaded piled raft on soft clay*. Paper presented at the The 12th Intl. Conf. of International Association for Computer Methods and Advances in Geomechanics (IACMAG).

Bajad, S., & Sahu, R. (2009). Time dependent settlement of piled raft foundation: Darmstadt Geotechnics.

Banadaki, A. D., Ahmad, K., & Ali, N. (2012). Initial Settlement of Mat Foundation on Group of Cement Columns in Peat–Numerical Analysis. *Electronic Journal of Geotechnical Engineering, 17*, 2243-2253.

Barksdale, R., & Bachus, R. (1983). *Design and Construction of Stone Columns Volume II, Appendixes*: Federal Highway Administration Washington, DC, USA.

Black, J., Sivakumar, V., Madhav, M., & Hamill, G. (2007). Reinforced stone columns in weak deposits: laboratory model study. *Journal of geotechnical and geoenvironmental engineering, 133*(9), 1154-1161.

Bowles, L. (1996). *Foundation analysis and design*: McGraw-hill.

Boylan, N., & Long, M. (2012). In situ testing of peat–a review and update on recent developments.

Boylan, N., & Long, M. (2013). Evaluation of peat strength for stability assessments.

BS 1377, P. (1990). British Standard Methods of Test for Soils for Civil Engineering Purposes, Part 2: Classification tests. *British Standards Institution, London*.

Cappa, R., Yniesta, S., Lemnitzer, A., Brandenberg, S. J., & Shafiee, A. (2015). Settlement estimations of peat during centrifuge experiments *IFCEE 2015* (pp. 152-160).

Chebet, F., & Kalumba, D. (2014). Laboratory Investigation on Re-Using Polyethylene (Plastic) Bag Waste Material for soil reinforcement in Geotechnical Engineering. *Civil Engineering and Urban Planning: An International Journal (CiVEJ), 1*.

Cherrier, H. (2006). Consumer identity and moral obligations in non- plastic bag consumption: a dialectical perspective. *International Journal of Consumer Studies, 30*(5), 515-523.

Chung, S., Kwag, J., Baek, S., & Lee, N. (2005). Performance of a medium tall building supported by a floating foundation on the Nakdong River deltaic deposit. *KSCE Journal of Civil Engineering, 9*(3), 187-195.

Chung, W., & Cascante, G. (2007). Experimental and numerical study of soil-reinforcement effects on the low-strain stiffness and bearing capacity of shallow foundations. *Geotechnical and Geological Engineering, 25*(3), 265-281.

Clapp, J., & Swanston, L. (2009). Doing away with plastic shopping bags: international patterns of norm emergence and policy implementation. *Environmental politics, 18*(3), 315-332.

Cunha, R., Poulos, H., & Small, J. (2001). Investigation of design alternatives for a piled raft case history. *Journal of geotechnical and geoenvironmental engineering, 127*(8), 635-641.

Deboucha, S., Hashim, R., & Alwi, A. (2008). Engineering properties of stabilized tropical peat soils. *Electronic Journal of Geotechnical Engineering, 13*, 1-9.

Dehghanbanadaki, A., Ahmad, K., & Ali, N. (2016). Experimental investigations on ultimate bearing capacity of peat stabilized by a group of soil–cement column: a comparative study. *Acta Geotechnica, 11*(2), 295-307.

Duraisamy, Y., Huat, B. B., & Aziz, A. A. (2007). Methods of utilizing tropical peat land for housing scheme. *American Journal of Environmental Sciences, 3*(4), 259-264.

EarthTalk®. (2010). Plastic Grocery Bags: How Long Until They Decompose? *Business Ethics*.

Fox, N. S., & Edil, T. B. (2001). Case Histories of Rammed Aggregate Pier Soil Reinforcement Construction over Peat and Highly Organic Soils *Soft Ground Technology* (pp. 146-157).

Gan, C., & Tan, S. (2003). *Some construction experiences on soft soil using light weight materials.* Paper presented at the 2nd International Conference on Advances in Soft Soil Engineering and Technology, Putrajaya, Malaysia.

Ghavami, K. (1995). Ultimate load behaviour of bamboo-reinforced lightweight concrete beams. *Cement and concrete composites, 17*(4), 281-288.

Gnanaharan, R., Janseen, J., & Arce, O. (1994). Bending strength of Guadua bamboo: Comparison of Different Testing Procedures.

Hashim, R., & Islam, S. (2008). Engineering properties of peat soils in Peninsular, Malaysia. *Journal of Applied Sciences, 8*(22), 4215-4219.

Hayashi, H., Yamazoe, N., Mitachi, T., Tanaka, H., & Nishimoto, S. (2012). Coefficient of earth pressure at rest for normally and overconsolidated peat ground in Hokkaido area. *Soils and Foundations, 52*(2), 299-311.

Huang, P.-T., Patel, M., Santagata, M. C., & Bobet, A. (2009). Classification of organic soils.

Huat, B. B., Prasad, A., Asadi, A., & Kazemian, S. (2014). *Geotechnics of organic soils and peat*: CRC Press.

Hungr, & Evans, S. (1985). An example of a peat flow near Prince Rupert, British Columbia. *Canadian Geotechnical Journal, 22*(2), 246-249.

Hungr, Evans, S., Bovis, M., & Hutchinson, J. (2001). A review of the classification of landslides of the flow type. *Environmental & Engineering Geoscience, 7*(3), 221-238.

Irsyam, M., Krisnanto, S., & Wardhani, S. (2008). Instrumented Full Scale Test and Numerical Analysis to Investigate Performance of Bamboo PIle-Mattress System as Soil Reinforcement for Coastal Embankment on Soft Clay. *Geotechnical Engineering for Disaster Mitigation and Rehabilitation*, 165-170.

Kalantari, B., & Huat, B. B. (2008). Peat soil stabilization, using ordinary portland cement, polypropylene fibers, and air curing technique. *Electron J Geotech Eng Bund J, 13*, 1-13.

Kalantari, B., & Huat, B. B. (2009). Precast stabilized peat columns to reinforce peat soil deposits. *Electron. J. Geotech. Eng, 14*.

Kalantari, B., Prasad, A., & Huat, B. B. (2011). Stabilising peat soil with cement and silica fume. *Proceedings of the Institution of Civil Engineers-Geotechnical Engineering, 164*(1), 33-39.

Kamali, B., & Hashim, R. (2010). Bamboo foundation mat for rubble mound breakwaters on mud deposits. *International Journal of the Physical Sciences, 5*(9), 1406-1410.

Kazemian, S., Asadi, A., Huat, B. B., Prasad, A., & Rahim, I. B. (2010). Settlement problems in peat due to their high compressibility and possible solution using cement columns *Forensic Engineering 2009: Pathology of the Built Environment* (pp. 255-264).

Kazemian, S., & Huat, B. B. (2009). Compressibility characteristics of fibrous tropical peat reinforced with cement column. *Electronic Journal of Geotechnical Engineering, 14*, 1-13.

Kenneth, S. S., Malburg. (2011). How Quickly Does Plastic Breakdown? The New Biodegradable Plastic Option. *Bright Hub*.

Khan, S. A., & Kamal, M. A. (2012). Design and construction of prestressed arch using plastic shoppers waste. *Materiales de Construcción, 62*(308), 597-606.

Lakkad, S., & Patel, J. (1981). Mechanical properties of bamboo, a natural composite. *Fibre Science and Technology, 14*(4), 319-322.

MacCulloch, F. (2006). Guidelines for the risk management of peat slips on the construction of low volume/low cost roads over peat. *Forestry Civil Engineering, Forestry Commission, Scotland*.

MacFarlane, I. C. (1969). Engineering characteristics of peat. *Muskeg Engineering Handbook. University of Toronto Press, Toronto, Ont*, 78-126.

Maoyi, F., & Baniak, R. (1995). *Bamboo production systems and their management.* Paper presented at the Propagation and Management. Bamboo, People and the Environment: Proceedings of the Vth International Bamboo Workshop and the IV International Bamboo Congress Ubud.

Mesri, G., & Ajlouni, M. (2007). Engineering properties of fibrous peats. *Journal of geotechnical and geoenvironmental engineering, 133*(7), 850-866.

Mohsenian, S., Eslami, A., & Kasaee, A. (2011). Geotechnical Aspects for Design and Performance of Floating Foundations *Geo-Frontiers 2011: Advances in Geotechnical Engineering* (pp. 56-65).

Mokhtari, M., & Kalantari, B. (2012). Soft soil stabilization using stone columns—A review. *Electronic Journal of Geotechnical Engineering, 17*, 1459-1456.

Munro, R. (2004). Dealing with bearing capacity problems on low volume roads constructed on peat. *Including case histories from roads projects within the ROADEX partner districts. The Highland Council, Transport, Environmental & Community Service*.

Munro, R., Evans, R., & Saarenketo, T. (2007). ROADEX II Project: Focusing on Low-Volume Roads in the European Northern Periphery. *Transportation Research Record: Journal of the Transportation Research Board*(1989), 292-299.

Murugesan, S., & Rajagopal, K. (2009). Studies on the behavior of single and group of geosynthetic encased stone columns. *Journal of geotechnical and geoenvironmental engineering, 136*(1), 129-139.

Nichol, D. (1998). *Construction over peat in Greater Vancouver, British Columbia*. Paper presented at the Proceedings of the Institution of Civil Engineers. Municipal engineer.

O'Kelly, B. C., & Pichan, S. P. (2013). Effects of decomposition on the compressibility of fibrous peat—A review. *Geomechanics and Geoengineering, 8*(4), 286-296.

Pichan, S., & O'Kelly, B. (2012). Effect of decomposition on the compressibility of fibrous peat *GeoCongress 2012: State of the Art and Practice in Geotechnical Engineering* (pp. 4329-4338).

Poulos, H. (2002). Simplified design procedure for piled raft foundations *Deep Foundations 2002: An International Perspective on Theory, Design, Construction, and Performance* (pp. 441-458).

Rahardjo, P. P. (2005). The use of bamboo and bakau piles for soil improvements and application of pile raft system for the construction of embankment on peats and soft soils. *Elsevier Geo-Engineering Book Series, 3*, 899-921.

Razali, S. N. M., Bakar, I., & Zainorabidin, A. (2013). Behaviour of peat soil in instrumented physical model studies. *Procedia Engineering, 53*, 145-155.

Roddier, D., Cermelli, C., Aubault, A., & Weinstein, A. (2010). WindFloat: A floating foundation for offshore wind turbines. *Journal of renewable and sustainable energy, 2*(3), 033104.

Sai, L. K., & Heng, T. N. (2016). Bamboo-Geotextile Buoyant System For Hefty Construction Over Deep Soft Subgrade.

Salleh, M. (1996). *The global environmental debate: The role of bamboo*. Paper presented at the Bamboo, People and Environment, propagation and management, edited by IV Rao and E. Widjaja, vol1. Proceedings of the fifth International Bamboo workshop and the Fourth International Bamboo Congress Ubud, Bali, Indonasia.

Service, U. S. N. P. (n. d.). Approximate Time it Takes for Garbage to Decompose in the Environment. *Marine Debris*.

Shaukat, A., & Kamal, M. (2010). Study of visco-elastic properties of shoppers waste for its reuse as construction material. *Construction and Building Materials, 24*(8), 1340-1351.

Sirlin, S., Paliou, C., Longman, R., Shinozuka, M., & Samaras, E. (1986). Active control of floating structures. *Journal of engineering mechanics, 112*(9), 947-965.

Suleiman, M. T., & White, D. J. (2006). Load transfer in rammed aggregate piers. *International Journal of Geomechanics, 6*(6), 389-398.

Tan, Y., Chow, C., & Clue, S. (2005). A design approach for piled raft with short friction piles for low rise buildings on very soft clay. *Geotechnical Engineering, 36*(1), 84-90.

Tastan, E. O., Edil, T. B., Benson, C. H., & Aydilek, A. H. (2011). Stabilization of organic soils with fly ash. *Journal of geotechnical and geoenvironmental engineering, 137*(9), 819-833.

Terzaghi, K., Peck, R. B., & Mesri, G. (1996). *Soil mechanics in engineering practice*: John Wiley & Sons.

Toh, C., Chee, S., Lee, C., & Wee, S. (1994). Geotextile-bamboo fascine mattress for filling over very soft soils in Malaysia. *Geotextiles and Geomembranes, 13*(6-7), 357-369.

Von Post, L., & Granlund, E. (1926). Peat resources in southern Sweden. *Sveriges geologiska undersökning, Yearbook, 335*(19.2), 1-127.

Warburton, J., Holden, J., & Mills, A. J. (2004). Hydrological controls of surficial mass movements in peat. *Earth-Science Reviews, 67*(1), 139-156.

Winter. (2014). Construction on soft ground using lightweight tyre bales. *Innovative and Sustainable Use of Geomaterials and Geosystems*, 1-8.

Winter, Johnson, P., & Reid, J. (2005). *Construction of road foundations on soft ground using lightweight tyre bales.* Paper presented at the Proceedings of International Conference on Problematic Soils.

Zhang, L., & O'Kelly, B. C. (2015). Effect of salt grain additions on fibrous peat consolidation. *Proceedings of the Institution of Civil Engineers-Ground Improvement, 168*(1), 14-21.

Zhang, L., & Zhao, M. (2014). Deformation analysis of geotextile-encased stone columns. *International Journal of Geomechanics, 15*(3), 04014053.

Zigang, L., & Xintu, L. (n.d.). The Global Distribution of Peat.