UNIVERSITI PUTRA MALAYSIA

RAPID STABILISATION OF HEMIC PEAT USING MELAMINE UREA FORMALDEHYDE POLYMER RESIN BY SOIL COLUMN METHOD

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By

MOHD NAZRIN BIN MOHD DAUD

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

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August 2019

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Generally, organic soil such as peat always associated with low strength properties and high compressibility behaviour that causes unfavourable load – settlement characteristic for any construction purpose. Conventionally, it is common to avoid these problematic soils area or in some cases soil replacement is used as a normal practice. However due to certain unavoidable circumference, rapid application method of soil stabilisation may attractively useful for rapid construction purposes, particularly during emergency or contingency in which time is greatly crucial. In this study, hemic peat soil has been stabilised using polymer resins such as melamine urea formaldehyde (MUF) polymer resins for the application of soil column reinforcement method. For this purpose, peat medium has been reinforced using powdered MUF (MUF-P) for rapid strength gains within maximum 72 hours or 3 days of curing period. Preliminary, strength development of treated peat soil has been studied using unconfined compressive strength (UCS) test. Physical properties of untreated and treated peat are among other important characterisation, as well as other mechanical properties that were also studied in this research. The results of laboratory test were important as input parameters for physical modelling test and finite element analysis. Physical modelling of scale-down laboratory model of the footing for area replacement ratio, α = 9.4%, 14.1% and 23.6% with various depths of 100 mm, 150 mm and 200 mm has been developed and simulated for load bearing test. Soil columns were treated with designated maximum MUF-P proportion under wet curing method before tested under load test at various depths for end-bearing foundation application. Additionally, finite element modelling using PLAXIS software was conducted for validation purpose. Parametric study such as bearing capacity and settlement reduction ratio had also been conducted accordingly. Overall, the result in this study has suggested that the stabilisation of peat soil using MUF-P resin polymer had significantly improved the strength properties, permeability characteristic and compressibility behaviour of peat within 72 hours of curing. Moreover, reinforcement of peat medium using soil column method with 350 kg/m^3 MUF-P binder had indicated that improvement of bearing capacity ratio (BCR) has increased proportionally to the increase of α

from 14.1% to 23.6%. Validation using finite element modelling and analysis also had confirmed that improvement of load – settlement behaviour of treated peat soil using soil column method had a considerable agreement with physical modelling results.

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

PENGUKUHAN CEPAT TANAH GAMBUT HEMIK DENGAN POLIMER RESIN *MELAMIN UREA FORMALDEHID* MENGGUNAKAN KAEDAH TIANG TANAH

Oleh

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Fakulti: Kejuruteraan

Umumnya, tanah organik seperti gambut seringkali dikaitkan dengan sifatnya yang mempunyai kekuatan ricih rendah serta kebolehmampatan tinggi yang menyebabkan ianya kurang sesuai untuk apa jua tujuan pembinaan. Secara konvensional, ia seringkali dielak dalam projek pembinaan atau dalam kes tertentu, tanah gantian mungkin akan digunakan. Bagaimanapun, dalam sesetengah situasi, kaedah penstabilan tanah yang cepat mungkin berguna untuk aplikasi pembinaan pantas, terutamanya bagi kes seperti dalam situasi kecemasan, bencana atau ancaman keselamatan yang mana masa adalah sangat kritikal. Dalam kajian ini, tanah gambut hemik telah diperkukuhkan dengan resin melamin urea formaldehid (MUF) menggunakan kaedah tiang tanah. Tanah yang diperkukuh menggunakan kaedah ini dirawat menggunakan serbuk MUF (MUF-P) untuk perawatan cepat dalam masa 72 jam. Kekukatan tanah yang terhasil telah diselidiki menggunakan ujian kekuatan mampatan tak terkurung (UCS). Ciri fizikal bagi tanah tak terawat dan terawat merupakan salah satu pencirian penting selain ciri mekanikal dalam kajian ini. Keputusan ujikaji makmal pula penting sebagai input untuk ujian model fizikal dan analisis unsur terhingga. Model fizikal untuk rekabantuk asas berskala makmal bagi nisbah luas gantian, α = 9.4%, 14.1% dan 23.6% dengan kedalaman 100 mm, 150 mm dan 200 mm telah dibangunkan dan disimulasi untuk ujikaji galas beban. Tiang tanah dirawat dengan kandungan MUF-P yang optimum dan diawet dalam keadaan basah sebelum ujikaji bebanan dilakukan pada kedalaman dan α yang pelbagai bagi aplikasi asas galas hujung. Selain itu, permodelan unsur terhingga menggunakan perisian PLAXIS telah dijalankan untuk tujuan pengesahan. Kajian parametrik seperti nisbah kapasiti galas dan pengurangan mendapan juga dilakukan. Secara keseluruhan, keputusan kajian mencadangkan bahawa penstabilan tanah gambut menggunakan MUF-P telah menunjukkan peningkatan ciri kekuatan, kebolehtelapan dan kebolehmampatan yang memberangsangkan selepas diawet dalam masa 72 jam. Tambahan pula, pengukuhan medium gambut menggunakan kaedah tiang tanah dengan komposisi 350 kg/m^3 MUF-P telah menunjukkan bahawa nisbah kapasiti bebanan tanggung telah meningkat secara berkala apabila α meningkat dari

14.1% ke 23.6%. Pengesahan menggunakan permodelan dan analisis unsur terhingga juga telah mengesahkan bahawa tiang tanah meggunakan tanah gambut yang terawat adalah bersaling kait dengan data ujikaji menggunakan permodelan fizikal.

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

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LIST OF ABBREVIATIONS

a_v	Coefficient of compressibility
b	Width of the scale down footing model
c	Cohesion
c′	Effective cohesion
c'_u	Effective cohesion (from CU tests)
c_u	Undrained shear strength
c_{uc}	Soil–cement columns shear strength
c_{uk}	Undrained shear strength of the columns
c_{us}	Shear strength of the surrounding soil
c_v	Coefficient of consolidation
d	Diameter of columns
e	Void ratio
e_o	Initial void ratio
g	Gram
k	Permeability coefficient or hydraulic conductivity
kg	Kilogram
km	Kilo Meter
kN	Kilo Newton
kNm	Kilo Newton minute
kN/m^2 or kPa	Kilo Newton per square meter or kilo Pascal
kN/m^3	Kilo Newton per cubic meter
l	Length of the scale down footing model = L
m	Metre
m_v	Coefficient of volume compressibility
q_u	Unconfined compressive strength
q_{uc}	Unconfined compressive strength of the treated columns
q_{ult}	Ultimate bearing capacity
q_{50}	Half of the compressive strength peak
rpm	Revolution per minute
s_u	Total undrained shear strength
t_n	Time
t_{50}	Time for 50% consolidation
u	Pore pressure
v	Poisson ratio
w	Water content
w_n	In-situ water content
w_{opt}	Optimum moisture content

A	Area or total cross-sectional area of the unit cell
A_c	Cross-sectional area of one column
ANOVA	Analysis of variance
B	Width of the footing or width of tank (chamber)
BCR	Bearing capacity ratio
BFS	Blast furnace slag
C	Cement
$CaCl_2$	Calcium chloride
C_c	Coefficient of curvature
CBR	California bearing ratio
CFG	Cement-fly ash-gravel
C_α	Secondary compression index
C_c	Compression index
$C_{c\varepsilon}$	Modified compression index (compression ratio)
CO_2	Carbon dioxide
C_r	Recompression index
$C_{r\varepsilon}$	Recompression ratio
C_s	Swelling index
C_u	Coefficient of uniformity
CU	Consolidated undrained (triaxial)
D	Diameter
DM	Deep mixing
D_o	Initial diameter
E	Modulus of elasticity
E_t	Tangent modulus
E_{50}	Secant modulus
EPA	Environmental Protection Agency
FEM	Finite element method
GWT	Ground water table
H	Height or height of the columns and tank (chamber)
Ha	Hectare
Hn	Humification index
H_{avg}	Average height
H_{dr}	Drainage height
H_o	Initial height
IFRC	International Federation of Red Cross/Red Crescent Societies
K_c	Strength ratio

L	Length of the footing or length of the tank (chamber)
LDVT	Load displacement transducer
LEED	Leading in Energy and Environmental Design Certification
LL	Liquid limit
LS	Linear shrinkage
L_o	Initial length
MDD	Maximum dry density
MF	Melamine formaldehyde
MPa	Mega Pascal
MSCS	Malaysian Soil Classification Systems
MUF	Melamine urea formaldehyde
MUF-L	Melamine urea formaldehyde (liquid)
MUF-P	Melamine urea formaldehyde (powder) with 10% melamine
MUF-PI	Melamine urea formaldehyde (powder) with 20% melamine
N	Loss of ignition
O	Organic
OC	Organic content
OMC	Optimum moisture content
OPC	Ordinary Portland cement
PF	Phenolic
PFA	Pulverised fuel ash
PI	Plasticity index
PL	Plastic limit
P_c or σ_c'	Pre-consolidation pressure
P_o	Overburden pressure
Pta	Amorphous or sapric peat
Ptf	Fibric or fibrous peat
Pth	Hemic or moderately peat
SC	Soil-cement
SCBA	Sugarcane bagasse ash
SEM	Scanning electron microscopy
T_{50}	Consolidation time factor
UCS	Unconfined compressive strength
UCT	Unconfined compression test
UF	Urea-formaldehyde
UU	Unconsolidated undrained (triaxial)
WDR	World Disaster Report

WFP	World Food Program
XRD	X-ray diffraction
α	Area replacement ratio or improvement area ratio (percentage)
β	Settlement reduction ratio
σ	Total stress
σ'	Effective stress
σ_1	Total major principal stress
σ_3	Total minor principal stress
ϕ	Internal friction angle
ϕ'	Effective internal friction angle
ϕ'_u	Effective undrained friction angle
ε	Strain
ε_{be}	Bedding correction
ε_{50}	Strain corresponds with q_{50}
ψ	Dilatancy angle
µs/cm	Microsecond per centimetre
Δe	Change in void ratio
λ	Dimensionless coefficient proposed by Bergado *et al.* (1996)
γ	Unit weight
γ_{dmax}	Maximum dry unit weight
γ_{dry}	Dry unit weight
γ_{sat}	Saturated unit weight
γ_{unsat}	Unsaturated unit weight
γ'	Effective unit weight
γ_w	Unit weight of water
%	percentage

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Generally, peat soil deposits can be distinguished based on their physical identification. They are the partly decomposed fragmented remains of plants that have accumulated under water and have humified. They are composed of more than 50% organic substances (Kalantari, 2013). Naturally, these organic deposits are highly moistened due to the presence of high-water table that is consequently translated to its problematic characteristics of low shear strength and high compressibility behaviour. The problematic behaviour of peat soil deposits always poses great concerns and engineering challenges to geotechnical engineers and researchers.

Additionally, peat soil shows other inferior engineering characteristics such as high liquid limit, low density, and poorly distributed grain size distribution compared to inorganic soils. Therefore, it is understandable that most of the time, engineers are trying to avoid any kinds of construction or civil engineering projects in peat soil area. Nevertheless, a significant amount of peat soil can be vastly found in many parts of the world, either in temperate or tropical region. Generally, tropical peat covers a total of 30 million hectares of the world land, where some 60% of it can be found in Southeast Asia. Malaysia alone, has about 8% of its total land (3 million hectares) covered with tropical peat (Duraisamy *et al.,* 2007; Kalantari, 2013). In western part of Johore, Malaysia for instance, peatland area currently serves as one of the important economic zones along with others most-developed region of western costal part of Peninsular Malaysia. Nowadays, hundreds of hectares of peat or organic land which were previously agricultural land are being transformed as housing and commercial lands (Ling *et al.,* 2014) due to the increasing demand for the fulfilment of socio-economic development.

As such, there is a strong sense among many geotechnical engineers and researchers to find ways to resolve this problematic soil by strengthening using various methods through considerable amount of time in research works for different specified purposes. Plentiful construction methods have been studied and some were implemented particularly for foundation construction or to support embankments for various construction projects of general purposes. However, in many cases post-construction bearing failures and large settlement remains continue to occur even after stabilisation work. Additionally, other methods of stabilisation, such as rapid stabilisation, may also yet to be explored for the benefit of future research, that are not only limited to certain application purposes.

1.2 Problem Statement

Population growth and economic activities increased intensely within past few decades in most parts of western coast of Malaysia Peninsular including lowland area due to limitation of suitable land. Therefore, it is likely inevitable to make full use of identifiably less favourable soils like peat that dominates most of this area. However, sustainable future growth is not only about the volume of economic development, but more importantly some unforeseen events, such as man-made or natural disaster, might require advancement in current soil improvement technology. Preliminarily, peat soil are composed of fibrous organic matters that are organic residues of plants formed through incomplete decomposition process. According to Jarret (1995), it is classified as an extreme form of soft soil that contains more than 75% of organic content. In Malaysia, peat soil, which are considered as problematic soil, made a significant appearance of about 8% of 3 million hectares of total land area in Malaysia. The west Malaysian peat exhibits low strength, very high compressibility, and low bearing capacity (Hashim and Islam, 2008). Traditionally, excavation – displacement or replacement, ground improvement, and reinforcement through preloading and vertical drains, stone columns, piles and light weight foundation system are among considerable options for peat soil stabilisation (Edil, 2003). However, all improvement methods are mostly applied for general use in engineering construction, but not intendedly studied for specific purpose such as rapid engineering application.

Organic soil such as peat can be found vastly in western costal area of Johore state. In this wetland region, Batu Pahat currently serves as the second largest township in Johore after Johore Bahru which is experiencing rapid development since the last decade. Hundreds of hectares of peat or organic land, which were previously agricultural land, are being developed as housing and commercial lands (Ling *et al.,* 2014). Over the years, industrial zones and public high learning institutions establishment along with constructions of two-lane highway, have become catalyst for rapid development and construction to meet both residential and commercial demands.

Additionally, the Kuala Lumpur International Airport 2 (KLIA2) which was constructed over peat soil medium also known to have long-standing issue of differential settlement. According to a report, suggestion to close down the airport for treatment works would not guarantee for the issue to not occur again, given the degree of soil settlement which was expected to be fully stabilised in five year times and has set aside some RM10 million a year for the programme (Bahari, 2014; The Malaysian Reserve, 2017). Previously, there was also a plan to spend over RM100 million to upgrade other airports in Malaysia including KLIA which is located near to peatland area that might require "astronomical" funding (Bahari, 2017; Yusof, 2019).

In West part of Malaysia, mostly peatland area is distributed along the west coast area. Pan Borneo Highway which is known to be a costly engineering project that involved construction of highway over soft ground. In a report, 70 per cent of about the RM12 billion cost will be spent on building the stretches that pass through peat soil (Tawie, 2016). Evidently, all this valuable construction projects on soft soil medium always associated with high pre-construction cost and problematic post construction settlement that need to be addressed in near future along with other consideration of newly developed rapid stabilisation technique within particular area of interest for specific purposes.

In general, stabilisation of material can be achieved effectively by adding chemical reactant to the material so that it can react rapidly thus bond them together to form strengthened material. This includes using Portland cement, lime, bitumen, fly ash and other materials, such as melamine resin and phenol formaldehydes resin (Bell, 1993). However, types of binder and stabilisation method to be chosen for depends on different purposes and specific conditions. They are also certain factors that should be considered and followed before making any selections of materials (Liu and Evett, 2006). Typically, military application, for instance, is mainly concerned with construction of pavement and airfield that only involve surface stabilisation of soft clay (Rafalko, 2006; Brandon *et al.,* 2004). At this moment, critical study on chemical admixture such as formaldehyde resin particularly for rapid application has been rare and uncommon to the peat soil. Notwithstanding the good results that polymers give in soil stabilisation, their use and non-traditional stabilisers in general is considered limited due to the lack of adequate studies and publications (Naeini and Ghorbanalizadeh, 2010).

Essentially, the application of rapid soil stabilisation concept previously concerned with construction of excess roads and airfields design in order to improve mobility on the ground since late 1940s (Brandon *et al.,* 2004) has been extended for more specific applications, such as humanitarian and disaster relief missions. In particular, the establishment of temporary shelter might require additional consideration such as improvement of ground condition. An initial assessment should also be carried out as soon as possible after the disaster occurs, while addressing any life-threatening or other critical needs Sandison and Davidson (2011). This requirement for rapid or instantaneous solution is in concurrent with the military specification which may also have a requirement to develop methods of strengthening soil to support rapid runway, roadway construction (Morefield *et al.,* 2004) and other possible preliminary geotechnical works, such as treatment of ground foundation. Ideally, maximum of 72 hours to achieve required strength after treatment could be considered acceptable under emergency condition during military operation (Rafalko *et al.,* 2008). Additionally, time effects are the main driving force for rapid stabilisation of soil with the goal to achieve a soil stabiliser that will produce the appropriate stabilised soil properties within 72 hours of treatment (Brandon *et al.,* 2004).

Since 1960s, deep mixing technique has steadily progressed and successfully applied in various parts of the world such in Japan, Europe and the US for solution of various problems in soft ground engineering. It has been applied, for instance, in the prevention of sliding failure, reduction of settlement, excavation support, controlling seepage, and preventing shear deformation (Porbaha, 1998). Eurosoilstab (2002) had highlighted that full interaction between columns and the intermediate unstabilised soil is assumed to occur if there are no initial ongoing movements in the natural ground where the structure is to be built. For an average value of the shear strength, stability can be calculated on the basis of cylindrical slip surfaces. This can be done provided that these columns are axially loaded, which applies for the active part of the slip surface, and that the maximum characteristic value of the undrained shear strength of the columns (c_u) is put between 50 to 100 kPa or in favourable cases at 150 kPa.

1.3 Objectives of the Study

By taking into account the requirement for rapid peat soil stabilisation for specific application using soil-columns method, the objectives of this research can be described as follows:

1. To characterise strength properties of peat soil through laboratory test for determination of rapid strength properties of hemic peat soil treated using melamine urea formaldehyde (MUF) polymer resins.
2. To model a laboratory-scaled load bearing test equipment and numerical modelling for soil-columns of treated hemic peat soil.
3. To evaluate load and settlement properties of hemic peat medium reinforced with treated peat soil-columns using physical model and load bearing test.
4. To validate load bearing characteristic and settlement behaviour of treated soil based on finite element analysis using PLAXIS simulation software.

1.4 Significance of the Study

Primarily, this study was conducted to establish new fresh look of knowledge on treatment method for peat soil in Malaysia using rapid soil stabilisation method. Currently, study on rapid soil stabilisation especially in Malaysia peat is uncommon and considered a new area of research which requires considerable attention among researchers. In general, western part of peninsular Malaysia, such as Batu Pahat in Johore, has always been a catalyst for economic development that is also found to be rich in hemic peat soil. Peat soil is known for its problematic properties with low strength characteristic. Thus, it has been a critical subject of geotechnical research for past few decades in this rapid developing region. Until recently, more studies on this particular area has to be refreshed considering recent development on infrastructures and economic advancement in the region along with other strategic issues when dealing with possible future of global disasters. Among other key development projects of infrastructure includes proposal of high-speed railway tracks and other significant construction projects, such as new educational township and airfield, to boost economic and education development in this strategic economic region.

Currently, there is no significant study on peat soil stabilisation such as newly research area of rapid treatment method especially using non-conventional binder other than cement and pozzolanic materials. Some of previous studies only focused on other soft soil such as silty clay, clay and sand (Ajayi-Majebi, 1991; Santoni *et al.,* 2003; Naeni and Ghorbanalizadeh, 2010, 2012). At this moment, critical study on chemical admixture such as formaldehyde resin particularly for rapid application has been rare and uncommon particularly to organic soil such as peat soil. More research regarding the use of non-traditional binder is needed in order to provide and support better understanding and information for the sake of sustainable future of geotechnical study in this area. Furthermore, conventional binder such as cement is also responsible for about 5% – 8% of global carbon dioxide (CO_2) emissions around the globe and is expected to grow 0.8 to 1.2% per year until it may reach 4.4 billion tonnes of productions in 2050 (World Business Council for Sustainable Development, 2010).

This study also principally aims to establish of new knowledge and connection on related issues to create a link between pure engineering applications with other potential areas of research such as for humanitarian, disaster relief mission, and to some extent for military requirement and specification. Specifically, instantaneous or rapid strength gain of soil foundation is primarily important criteria for establishment of temporary or transition post-disaster shelter or camp. Saunders (2011) had highlighted that an initial assessment should be carried out as soon as possible after the disaster occurs, while addressing any life-threatening or other critical needs. Though, maximum of 72 hours to achieve required strength after treatment could be considered acceptable under emergency condition during military operation (Rafalko, 2008).

Additionally, deep soil stabilisation technique is often an economically attractive alternative to other stabilisation methods such as removal of deep peat and use of piling foundation. Nowadays, deep soil stabilisation method is proven to be economical and requires minimum time (Islam and Hashim, 2010). The essential feature of deep soil stabilisation is that column of stabilised material is formed by mixing the soil in place with a binder and the interaction of binder with the soft soil leads to a material which has better engineering properties than the original soil (Hebib and Farrell, 2003). Beneficially, this method could avoid the need of natural soil replacement and eliminate excessive waste material problem. Compared to traditional techniques, the cost of transporting the spoils decreases because the soil is mixed in situ rather than replaced, and the net quantity of excess material is considerably less (Porbaha *et al.,* 1998). In this study, stabilised soil columns performance was tested and evaluated using physical model which is commonly used for soft soil stabilisation study.

1.5 Scope and Limitation of the Study

Generally, the peat soil was treated and tested in this study based upon various types of laboratory test with melamine urea formaldehyde (MUF) polymer resin before stabilised using specified soil columns method of stabilisation within designated curing period of maximum 72 hours or 3 days after treatment (Rafalko, 2006; Brandon *et al.,* 2004). This was based on unconfined compression strength test data of undrained shear strength behaviour, which also should simulate if not better, the same result when using isotropic triaxial test procedure according to EuroSoilStab (2002). Subsequently, treated soil using optimum proportion was further studied and simulated using laboratory scale physical model for load bearing test and compared to simulation analysis of finite element method (FEM) using PLAXIS software. Tropical hemic peat soil was selected throughout the tests after considering its local availability and important contribution to socioeconomic impact, as well as its medium peat characteristic.

Preliminarily, basic properties of untreated and treated peat soil were studied to support primary data from various research works previously done in this area for determination of strength parameters. The main laboratory test conducted in this study was initially for peat soil treated using liquid type of MUF polymer resin and subsequently extended to powdered MUF polymer resin as a fulfilment of additional study on mixing condition and method of curing. All strength tests were conducted using unconfined compression strength (UCS) test for two different types of curing method; dry and wet curing. Further strength parameters determination was obtained using isotropic triaxial test, and other important engineering properties test such as compressibility and permeability were also conducted in the study to support the finding.

The performance of laboratory scale soil columns treated with MUF polymer resin has been simulated using physical models with provision of adequate boundary condition. In this study, three types of soil columns configurations were explored accordingly based on strip footing of group columns. Load bearing test was executed for different depths and columns spacing to replicate group columns bearing capacity and settlement behaviours under axial load for end bearing application. Further details on specification are discussed accordingly in Chapter 3.

Simulation analysis using finite element method was primarily based on previous published research data for strength properties data input with exception of newly established strength parameter characteristics of MUF treated peat column. For this reason of study, PLAXIS 3D version was utilised to optimise the accuracy of analysis through 3-dimensional modelling of the footing and soil system. However, only Mohr-Coulomb theory was included in simulation considering limited availability of soil properties data for more advanced analysis execution.

1.6 Thesis Organisation

Generally, this thesis is presented in 5 chapters including introduction part (Chapter 1). The second part in Chapter 2 elaborates the literature review on peat, stabilisation method, previous research review, characterisation, physical and numerical modelling and test. In Chapter 3, important research methodology is discussed accordingly to accomplish the objectives of the research as described Consequently chapters.

The following chapter (Chapter 4) deals with results and analysis, describing significant findings previously conducted using various types of laboratory test, physical modelling and experimental test, and also numerical modelling and analysis as described in Chapter 3. Concluding remarks are described elaborately in final chapter (Chapter 5) along with other discussions related recommendation for future study.

REFERENCES

Adon, R., Bakar, I., Wijeyesekera, D. C., & Zainorabidin, A. (2013). Overview of the sustainable uses of peat soil in Malaysia with some relevant geotechnical assessments. *International Journal of Integrated Engineering*, 4(4): 38–46.

Ajayi-Majebi, A., Grissom, W. A., Smith, L. S., & Jones, E. E. (1991). Epoxy-resin-based chemical stabilization of a fine, poorly graded soil system. *Transportation Research Record*, (1295): 95-108.

Ajlouni, M. A. (2000). *Geotechnical properties of peat and related engineering problems*. (Doctoral dissertation). University of Illinois at Urbana-Champaign.

Al-Khanbashi, A., & El-Gamal, M. (2003). Modification of sandy soil using waterborne polymer. *Journal of Applied Polymer Science,* 88(10): 2484-2491.

Al-Raziqi, A. A., Huat, B. B. K., & Munzir, H. A. (2003). Proceedings from 2nd International Conference on Advances in Soft Soil Engineering and Technology, 2-4 July 2003: *Index Properties of Some Tropical Peat and Organic Soils*. Putra Jaya, Malaysia.

Alwi, A. (2007). *Ground Improvement on Malaysian Peat Soils using Stabilized Peat Column Techniques*. (Doctoral dissertation). University of Malaya, Kuala Lumpur.

American Society for Testing and Materials (ASTM). (1997). *Annual Book of ASTM Standards: Soil and Rock*. Philadelphia: ASTM.

Aminur, M. R., Kolay, P. K., Taib, S. N. L., Mohd Zain, M. I. S., & Kamal, A. A. (2011). Physical, geotechnical and morphological characteristics of peat soils from Sarawak. *Journal - The Institution of Engineers, Malaysia,* 72(4): 12-16.

Anderton, G. L., Iv, E. S. B., Mann, T. A., Newman, J. K., Baylot, E. A., Miller, D. K., & Mason, Q. (2008). *Technology Demonstration Geotechnical and Structures Laboratory Joint Rapid Airfield Construction (JRAC) 2007 - Technology Demonstration, (July)*. Annual Meeting, January 2008, Washington, D.C.

Arasan, S., Fatih, I., Akbulut, R. K., Zaimo˘glu, A. S., & Nasirpur, O. (2015). Rapid Stabilization of Sands with Deep Mixing Method Using Polyester. *Periodica Polytechnica Civil Engineering*, 59(3): 405-411.

Arora, H. S., & Scott, J. B. (1974). Chemical stabilization of landslides by ion exchange. *California Geology,* 27: 99-107.

Axelsson, K., Johanson, S. E., & Anderson, R. (2002). *Stabilization of Organic Soils by Cement and Pozzolanic Reaction: Feasibility study*. Swedish Deep Stabilization Research Centre, Report 3, English Translation; 2002:15 - 16.

Bahari, B. (2014). Retrieved 12 August 2019 https://www.nst.com.my/news/2015/09/mahb-klia2-soil-issue-will-be-settled-5-years.

Bahari, B. (2017). Retrieved 13 August 2019 https://www.nst.com.my/business/2017/06/249094/mahb-plans-expansion-klia.

Bell, F. G. (1993). *Engineering Treatment of Soil*. London: E and FN Spon.

Bergado, D. T., Anderson, L. R., Miura, N., & Balasubramania, A. S. (1996). *Soft Ground Improvement in Lowland and Other Environments.* New York: ASCE Press.

Bitir, A. C., Musat, V., & Larsson, S. (2015). *Laboratory Methods used to Assess the Mechanical Properties of Soft Soils Improved by Deep Mixing (English Translation).* The Bulletin of the Polytechnic Institute of Iaşi. Gheorghe Asachi Technical University of Iaşi, Romania.

Black, A. J., Sivakumar, R. M., & Hamil, G. A. (2007). Reinforced stone column in weak deposit: laboratory model study. *J. Geotechn. and Geoenvironmental Eng. ASCE,* 9: 1154–1161.

Bolander, P. (1999). Laboratory testing of non-traditional additives for stabilization of roads and trail surfaces. *Transportation Research Record*, 2(1652): 24-31.

Bono, A., Beng, Y. K., & Siambun, N. J. (2003). Melamine – urea – formaldehyde (MUF) resin : the effect of the number of reaction stages and mole ratio on resin properties, (July). *Jurnal Teknologi,* 38(F): 43–52. http://doi.org/10.11113/jt.v38.508.

Borchardt, G. (1984). *Stabilization of Landslides: Effects of Various Chemicals on the Laboratory Shear Strength of an Expansive Soil*. Rep. No. Special Report 155, California Department of Conservations, Division of Mines and Geology: Sacramento, CA.

Borrmann, M. (1992) *Historische Pfahlgründungen. Materialien zur Bauforschung und Baugeschichte, Heft 3.* Karlsruhe: Institut für Baugeschichte der Universi- tät Karlsruhe.

Bouassida, M., de Buhan, P., & Dormieux, L. (1995). Bearing capacity of a foundation resting on a soil reinforced by a group of columns. *Géotechnique*, 45(1): 25-34.

Bouassida, M., Jellali, B., & Lyamin, A. V. (2014). “Ultimate Bearing Capacity of a Strip Footing on Ground Reinforced by a Trench, (November)”. http://doi.org/10.1061/(ASCE)GM.1943-5622.0000418.

Brandon, T. L, Brown, J. J, & Daniels, W. L. (2009). *Rapid Stabilization / Polymerization of Wet Clay Soils; Literature Review*. Air Force Research Laboratory Air Force Materiel Command 139 Barnes Drive, Suite 2, Tyndall Air Force Base, Flourida, U.S.

British Standard Institution (1990). BS 1377, 1-8: 1990. Method of Test for Soils for Civil Engineering Purposes.

Broms, B. B. (1991). *Stabilization of Soil with Lime Columns.* In Hsai-Yang Fang (Ed.), *Foundation Engineering Handbook 2nd Edition* (pp.c833-853). New York: Van Nostrand Reinhold.

Broms, B. B. (2000). Proceedings from 4th Int. Conf. on Ground Improvement Geosystems. Keynotes Lecture: *Lime and Lime/Columns. Summary and Visions.* Helsinki.

Broms, B. B. (2003). *Deep Soil Stabilization: Design and Construction of Lime and Lime/Cement Columns.* Royal Institute of Technology: Stockholm.

Bruce, D. A., Bruce, M. E., & DiMillio, A. F. (1998). Deep mixing method: A global perspective. *ASCE,* 68(12): 38-41.

Coduto, P. D., Yeung, M. C. R., & Kitch, W. A. (2010). *Geotechnical Engineering, Principles and Practices.* New Delhi: PHI Learning Private Limited.

Crist, R. H., Martin, J. R., Chonko, J., & Crist, D. R. (1996). Up- take of metals on peat moss: an ion exchange process. *Environmental Science & Technology,* 30(8): 2456-2461.

Das, B. M. (2010). *Principles of Geotechnical Engineering*. U.S: Cengage Learning.

Deboucha, S., Hashim, R., & Alwi, A. (2008). Engineering properties of stabilized tropical peat soils. *Electronic Journal of Geotechnical Engineering,* 13: 1–9. http://doi.org/10.3923/jas.2008.4215.4219.

Defense Support to Foreign Disaster Relief (DSFDR) (2011). Office of the Assistant Secretary of Defense. Department of State, Office of Crisis Management, JTF: Washington, D.C.

Dehghanbanadaki, A., Ahmad, K., Ali, N., Khari, M., Alimohammadi, P., & Latifi, N. (2013). Stabilization of soft soils with deep mixed soil columns - general perspective*. Electronic Journal of Geotechnical Engineering,* 18 B(Dm): 295–306.

Duraisamy, Y., Huat, B. B. K., & Aziz, A. A. (2007). Engineering properties and compressibility behavior of tropical peat soil. *American Journal of Applied Sciences,* 4(10): 768–773.

Duraisamy, Y., Huat, B. B. K., Muniandy, R., & Aziz, A. A. (2008). Compressibility behavior of fibrous peat reinforced with cement columns. *ICCBT- E,* (09): 93-110.

Edil, T. B. (2003). Proceedings from 2nd International Conference on Advances in Soft Soil Engineering and Technology: *Recent Advances in Geotechnical Characterization and Construction Over Peats and Organic Soils*. Putrajaya, Malaysia: UPM Press.

Ehsan, S. D. (2015). Deep mixing columns. *Pertanika Journal of Scholarly Research Reviews,* 2015(1): 8–17.

Enck, C. (2013). *LEED Version 4 for Building Design and Construction Manual - Ballot Version.* Green Building Inc.: Vermont, US.

Engineering and Design Laboratory Soil Testing. Engineer Manual No. 11102-2-1906, (1990), U.S. Department of the Army: United States.

EuroSoilStab. (2002). *Development of Design and Construction Methods to Stabilise Soft Organic Soils: Design Guide Soft Soil Stabilisation. CT97-0351. Project No. BE 96-3177.* Industrial & Materials Technologies Programme (Brite- Euram III), European Commission.

Farouk, A., & Shahien, M. M. (2013). Ground improvement using soil-cement columns: experimental investigation. *Alexandria Engineering Journal,* 52(4): 733–740.

Farrell, E. R., O'Neill, C., & Morris, A. (1994). *Changes in the Mechanical Properties of Soils with Variation in Organic Content. In Advances in Understanding and Modeling the Mechanical of Peat*, Rotterdam: Balkema.

Fattah, M. Y., & Majeed, Q. G. (2009). Behaviour of Encased Floating Stone Columns. *Eng. and Tech. Journal*, 27(7): 1404-1421.

Fong, S. S., & Mohamed, M. (2007). Chemical characterization of humic substances occurring in the peats of Sarawak, Malaysia. *Organic Chemistry*, 38(6): 967–976.

Formaldehyde: Structure of the World Capacity Broken Down oy Region, 2012. Retrieved from https://mcgroup.co.uk (5th June 2016).

Ganasan, R., Lim, A. J. M. S., & Wijeyesekera, D. C. (2016). Physical and software modelling for challenging soil structure interaction. *ARPN Journal of Engineering and Applied Sciences,* 11(6): 3668–3676.

Gopal, R. J., Singh, S., & Das, G. (1983). Chemical stabilization of sand comparative studies on urea-formaldehyde resins as dune sand stabilizer and effect of compaction on strength. *Indian Society of Desert Technology*, 8(2): 13-19.

Guidelines for Construction on Peat and Organic Soils in Malaysia. (2015). Construction Research Institute of Malaysia: Kuala Lumpur.

Gunther, R., Walter, D., Armin, O. G., & Albrecht, H. (2002). *Formaldehyde in Ullmann's Encyclopedia of Industrial Chemistry*. Weinheim: Wiley-VCH Verlag GmbH & Co.

Hanrahan, E.T. (1994). Proceedings from Institution Civ. Engrs. Water Maritime & Energy: *Discussion on Major Canal Reconstruction in Peat.* London: ICE Publishing.

Hashim, R., & Islam, S. (2008). Engineering Properties of Peat Soils in Peninsular, *Malaysia. J. Appl. Sci*., 2008(17): 1-5.

Hebib, S., & Farrell, E. R. (2003). Some experiences on the stabilization of Irish peats. *Canadian Geotechnical Journal,* 2003(40): 107-120.

Hobbs, N. B. (1986). Mire morphology and the properties and behaviour of some British and foreign peats. *Quart. J. of Eng. Geol*., 1986(19): 7-80.

Holm, G., Andréasson, B., Bengtsson, P. E., Bodare, A., & Eriksson, H. (2002). *Mitigation of Track and Ground Vibrations Induced by High Speed Trains at Ledsgård, Sweden*. Swedish Deep Stabilization Research Centre. Report 10: Linköping.

Holm, G. (2001). Deep Mixing. Soft Ground Technology. *ASCE Journal*, Geotechnical Special Publication No. 112: 105-122.

Hse, C.Y., Feng, F., & Hui, P. (2008). Melamine-modified urea formaldehyde resin for bonding particleboards. *Forest Products Journal,* 58(4): 56-61.

Huat, B. B. K., Sew, G.S., & Ali, F. H., (2004). *Organic and Peat Soils Engineering*. Serdang: University Putra Malaysia Press.

Huat, B. B. K., Kazemian, S., Prasad, A. & Barghchi, M. (2011). State of an Art Review of Peat: General Perspective. *International Journal of the Physical Sciences,* 6(8): 1988-1996.

Islam, S., & Hashim, R. (2010). Behaviour of stabilized peat: a field study. *Journal of Scientific Research and Essays,* 5(17): 2366-2374.

Islam, S., & Hashim, R. (2010). Stabilization of peat soil by soil-column technique and settlement of the group columns. *International Journal of Physical Sciences*, 5(9): 1411–1418.

Ismail, A. B. (1984). Proceedings from Workshop on Classification and Management of Peat in Malaysia: *Characterisation of Lowland organic soil in Peninsular Malaysia.* Ed. Pushparajah. Malaysian Soil Sci. Society: Serdang, Malaysia.

Jacobson, J. R., Filz, G. M., & Mitchell, J. K. (2005). *Factors Affecting Strength of Lime-Cement Columns Based on a Laboratory Study of Three Organic Soils. Deep Mixing '05.* Paper presented in International conference on deep mixing best practice and recent advances. 2005.

Jamil, M. A., Chow, W. T., Chan, Y. K., & Yew, S. K. (1989). Proceedings from the National Workshop Peat Research Development, MARDI: *Land Use of Peat in Peninsular Malaysia.*

Janz, M., & Johansson, S. E. (2002). *The Function of Different Binding Agents in Deep Stabilization.* Swedish Deep Stabilization Research Centre, Report 9, Linkoping: Sweden.

Jarret, P. M. (1995). *Site Investigation for Organic Soils and Peat.* JKR Document. Public Work Department Malaysia: Kuala Lumpur.

Johari, N. N., Bakar, I., & Aziz, M. H. A. (2015). “Consolidation parameters of reconstituted peat soil: oedometer testing. Applied mechanics and materials”, 773-
774, pp.1466–1470.

Juha, F., Leena, K., & Pyry, P. (2018). Mass Stabilization as a Ground Improvement Method for Soft Peaty. Peat, In Bülent Topcuoğlu and Metin Turan, (Ed.), *Peat.* London: IntechOpen Limited. DOI: 10.5772/intechopen.74144.

Kalantari, B., & Huat, B. B. K. (2008). Peat stabilization using ordinary portland cement, polypropylene fibers, and air curing techniques. *Electronic Journal of Geotechnical Engineering,* (2008)13: 1-13.

Kalantari, B., & Huat, B. B. K. (2009). Precast stabilized peat columns to reinforce peat soil deposits. *Electron. J. Geotech. Eng*, 14: 1–15.

Kalantari, B. (2010). *Stabilization of Fibrous Peat using Ordinary Portland Cement and Additives.* (Doctoral dissertation). University of Putra Malaysia.

Kalantari, B. (2013). Civil engineering significant of peat. Global*. Journal of Researches in Engineering*, 13(2): 26–28.

Kazemian, S., Huat, B. B. K., Prasad, A., & Barghchi, M., (2011) “A State of Art Review of Peat: Geotechnical Engineering Perspective”, Vol 6 Iss: 8, pp.1974–1981. http://doi.org/10.5897/IJPS11.396.

Kazemian, S., & Huat, B. B. K. (2012). “Undrained Shear Characteristics of Tropical Peat Reinforced with Cement Stabilized Soil Column”, pp.753–759. http://doi.org/10.1007/s10706-012-9492-7.

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

Kempfert, H. (2003). *Ground Improvement Methods with Special Emphasis on Column-Type Techniques*. International Workshop on Geotechnics of Soft Soils: Germany.

Kempfert, H. G., & Gebreselassie, B. (2006). *Excavations and Foundations in Soft Soils.* New York: Springer, Berlin Heidelberg.

Kitazume, M., Ikeda, T., Miyajima, S., & Karastanev, D. (1996). Proceedings from 2nd Int. Conf. on Ground Improvement Geosystems, Tokyo: *Bearing Capacity of Improved Ground with Columns Type DMM*. Proc. IS-Tokyo'96., 503-508. A. A Rotterdam: Balkema.

Kitazume, M., Okano, K., & Miyajima, S. (2000). Centrifuge model tests on failure envelope of column type deep mixing method improved ground. *Soils and Foundations,* 40(24): 43-55.

Kitazume, M., & Terashi, M. (2013). *The Deep Mixing Method*. Leiden: CRC Press.

Kolay, P., & Pui, M. (2010). Peat stabilization using gypsum and fly ash. *Feng.Unimas.My,* 1(2): 1–5.

Kwa, S. F., Kolosov, E. S., & Fattah, M. Y. (2018). Ground improvement using stone column construction encased with geogrid. *Construction of Unique Buildings and Structure,* 3(66): 45-59.

Liu, C., & Evett, J. B. (2006). *Soil Properties: Testing, Measurement and Calculation 6 Edition.* NJ, U.S: Prentice Hall.

Liu, M., (2017) "RSC Advances Characterization of the Crystalline Regions of Cured". http://doi.org/10.1039/c7ra08082d.

Majeed, Q. G. (2008), *Assessment of Load Capacity of Reinforced Stone Column Embedded in Soft Clay.* (M.Sc. thesis), Building and Construction Engineering Department, University of Technology, Baghdad.

Mass stabilization Manual. (2005). ALLU Finland: Orimattila, Finland.

Mccabe, B. A., Bai, B. A., & Miei, C. (2007). *Ground Improvement Using the Vibro-Stone Column Technique*. Engineers Ireland West Region and the Geotechnical Society of Ireland: NUI Galway.

McManus, K., Hassan, R., & Sukkar, F. (1997). Proceedings from Conference on Recent Advances in Soft Soil Engineering, ed. Huat and Bahia 1997: *Founding Embankments on Peat and Organic Soils.* Sarawak.

Mesri G, & Castro A. (1987). The Cα/Cc concept and ko during secondary *compression. J. Geotechn. Eng.*, 113 (3), 230–247.

Mesri, G., & Ajlouni, A. M. (2007). Engineering properties of fibrous peats. *J. Geotechnic. and Geoenvironmental Eng. ASCE,* 133(7): 850–864.

Morefield, S. W., & Mcinerney, M. K., Hock, V. F., Marshall, Jr., O. S. (2004). Rapid soil stabilization and strengthening using electrokinetic. *Report Documentation Page*, (October). http://Doi.Org/10.1142/9789812772572.

Mosely, M. P., & Kirsch, K. (2004). *Ground Improvement.* 2nd ed., New York: Spon Press.

Muntohar, A. S., Rahman, M. E., & Islam, M. S. (2013). A numerical study of ground improvement technique using group of soil-column on peat. *Pertanika J. Sci. & Technol.,* 21(2): 625-634.

Muntohar, A. S, Widianti, A., Edi, H., & Diana, W. (2013). Engineering properties of silty soil stabilized with lime and rice husk ash and reinforced with waste plastic fiber. *Journal of Materials in Civil Engineering,* 25(9): 1260-1270.

Naeini, S. A., & Ghorbanalizadeh, M. (2010). Effect of wet and dry conditions on strength of silty sand soils stabilized with epoxy resin polymer. *Journal of Applied Science,* (2010)22: 2839-2846.

Naeini, S. A., Naderinia, B., & Izadi, E. (2012). Unconfined compressive strength of clayey soils stabilized with waterborne polymer. *KSCE Journal of Civil Engineering,* 16(6):943–949. http://doi.org/10.1007/s12205-012-1388-9.

Newman, J. K., & White, D. J. (2008). *Rapid Assessment of Cement/Fiber Stabilized Soil Using Roller-Integrated Compaction Monitoring. 87th Annual Meeting, January 2008.* Washington, D.C.: Transportation Research Board.

Newman, K., & Tingle, J. S. (2004). Proceedings from FAA Worldwide Airport Technology Transfer Conference: *Emulsion Polymers for Soil Stabilization.* Atlantic City, New Jersey: Transportation Research Board.

Nik Daud, N. S., & Mohd Daud, M. N. (2015). Characterization of peat soil treated with polymer resin by unconfined compressive strength test. *Journal of Advanced Civil Engineering Practice and Research,* 2015(1): 11-17.

Nikookar, M., Hares, N., & Arabani, M. (2013). Proceedings from 7th SASTech Conference: *Unconfined Compressive Strength of Lime- Stabilized Peat Unconfined Compressive Strength of Lime-Stabilized Peat.* Bandar-Abbas, Iran: Khavaran Institute of Higher Education.

Niroumand, H., Kassim, K. A., & Yah, C. S. (2011). Soil improvement by reinforced stone columns based on experimental work. *Electronic Journal of Geotechnical Engineering,* 16 L: 1477–1499.

Noto, S. (1991). *Peat Engineering Handbook. Civil Eng. Res. Inst.* Hokkaido: Hokkaido Development Agency, Prime Minister's Office, Japan.

Okumura, T. (1997). Proceedings from the IS-Tokyo´96, 2nd Int. Conf. on Ground: *Deep Mixing Method in Japan*. *Japanese* Geotechnical Society: Japan.

Oldham, J. C., Eaves, R. C., & White, Jr. D. W. (1977). *Materials Evaluated as Potential Soil Stabilizers. Rep. No. Miscellaneous Paper S-77-15*, US Army Engineer, Waterways Experiment Station: Vicksburg, Miss.

Omine, K., Ochiai, H., & Bolton, M. (1999) Proceedings from the International Conference on Dry Mix Methods for Deep Soil Stabilization: *Homogenization Method for Numerical Analysis of Improved Ground with Cement-Treated Soil Columns.* Stockholm: CRC Press.

Peck, R. B., Hanson, W. E., & Thornburn, T. H. (1974). *Foundation Engineering.* New York: John Wiley and Sons, Ltd.

Pizzi, A. (1994). Melamine Formaldehyde Adhesives. In Pizzi, A. and Mittal, K. L. (Ed.), *Handbook of Adhesives Technology.* New York: Marcel Dekker Inc.

PLAXIS 2D Material Models Manual. (2008). P.O Box 572, 2600 AN Delft, The Netherlands.

Porbaha, A., & Bouassida, M. (2004). Proceedings from International Conference on Geotechnical Engineering: *Bearing Capacity of Foundations Resting on Soft Ground Improved by Soil Cement Columns.* UAE: University of Sharjah.

Porbaha, A., Shibuya, S., & Kishida, T. (2000). Proceedings from the Institution of Civil Engineers - Ground Improvement: State of the Art in Deep Mixing Technology. Part III: geomaterial characterization. http://doi.org/10.1680/grim.2000.4.3.91.

Porbaha, A. (1998). State of the art in deep mixing technology: basic concepts. *Ground Improvement,* 2(2): 81–92. http://doi.org/10.1680/gi.1998.020204.

Post-disaster Shelter: Ten Designs (2013). International Federation of Red Cross and Red Crescent Societies: Geneva, Switzerland.

Pourakbar, S. (2015). Deep mixing columns. *Pertanika Journal of Scholarly Research Reviews,* 1(1): 8 – 17.

Powrie, W. (1997). *Soil Mechanics Concept and Applications.* London: E & FN Spon.

Rafalko, S. D. (2006). “Rapid Soil Stabilization of Soft Clay Soils for Contingency Airfields” Virginia Polytechnic Institute and State University Blacksburg, VA. Pg 5. https://doi.org/10.3141/2026-05.

Rafalko, S. D., Brandon, T. L., Filz, G. M., & Mitchell, J. K. (2008). Rapid chemical stabilization of soft clay soils. *Journal of the Transportation Research Board,* No. 2026: 39-46.

Rahman, M. A., Kolay, P. K., & Taib, S. N. L. (2011). Utilization of fly ash in local Sarawakian peat soil stabilisation. *Australian Geomechanics*, 46(3): 73-85.

Rahman, Z. A., Sulaiman, N., Rahim, S. A., Idris, W. M. R, & Lihan, T. (2016). Effect of cement additive and curing period on some engineering properties of treated peat soil. *Sains Malaysiana,* 45(11): 1679–1687.

Rashid, A. S. A., Bunawan, A. R., & Said, K. S. M. (2017). The deep mixing method: bearing capacity studies. *Geotechnical and Geological Engineering,* 35(4): 1271-1298.

Ringqvist, L., Holmgren, A., & Őborn, I. (2002). Poorly humified peat as an adsorbent for metals in wastewater. *Water Research,* 36(9): 2394-2404.

Said, J. M., & Taib, S. N. L. (2009). Peat stabilization with carbide lime. *UNIMAS E-J. Civ. Eng*., 1(1): 1–6.

Salençon, J. (1990). An introduction to the yield design theory and its applications to soil mechanics. *Eur. J. Mech. A. Solids,* 9(5): 477–500.

Sandison, P., & Davidson, S. (2011). The Core Standards. In Wilson, D. (Ed.), *Humanitarian Charter and Minimum Standards in Disaster Response* (pp. 48-72). Geneva, Switzerland: The Sphere Project.

Santoni, R. L., Tingle, J. S., & Webster, S. L. (2002). Stabilization of silty sand with nontraditional additives. *Transportation Research Record: Journal of the Transportation Research Board,* 1787(1): 61-70.

Santoni, R. L., Tingle, J. S., & Nieves, M. (2005). Accelerated strength improvement of silty sand with nontraditional additives. *Transportation Research Board,* 1936(1): 34-42.

Saunders, G. (2011). Minimum Standards in Shelter, Settlement and Non-Food Items. In Wilson, D. (Ed.), *Humanitarian Charter and Minimum Standards in Disaster Response* (pp. 239-267). Geneva, Switzerland: The Sphere Project.

Schaefer, V. R., Abramson, L. W., Drumheller, J. C., & Sharp, K. D. (1997). *Ground Improvement, Ground Reinforcement and Ground Treatment: Developments 1987-1997*. American Society of Civil Engineers: Reston, VA.

Sha’abani, M., & Kalantari, B. (2012). Mass stabilization technique for peat soil – a review. *ARPN Journal of Science and Technology,* 2(5): 512–516.

Shahu, J. T., & Reddy, Y. R. (2011). Clayey soil reinforced with stone column group: model tests and analyses. *Journal of Geotechnical & Geoenvironmental Engineering,* 137(12): 1265-1274.

Skempton, A. W., & Petley, D. J. (1970). Inorganic loss and other properties of peats and clays from avonmouth, kings lynn & cranberry moss. *Geotechniques*, 20(4): 343-356.

Sobhan, K., Reddy, D. V., & Ramirez, J. C. (2012). Proceedings from LACCEI: (Editor), Megaprojects: Building Infrastructure by fostering engineering collaboration, efficient and effective integration and innovative planning Panama City, Panama: *Cement Stabilization of Organic Subgrades for Pavement Preservation*. Panama: Universidad Tecnologica De Panama.

Souliman, M. I., & Zapata, C. (2011). International case studies of peat stabilization by deep mixing method. *Jordan Journal of Civil Engineering,* 5(3): 424–430.

Sun, Q., Hse, C., & Shupe, T. F. (2014). Effect of different catalysts on urea-formaldehyde resin synthesis. *Journal of Applied Polymer Science,* 40644(131): (1-7).

Sunnetcioğlu, M. E. (2012). *A Laboratory Model Study on Settlement Reduction of Stone Columns in Soft Clay.* (Master dissertation). Middle East Technical University, Turkey.

Talib, M. K. M. (2016). *Effectiveness of Sugarcane Bagasse Ash (SCBA) Utilization in Peat Stabilization*. (Doctoral dissertation). Kyushu University Fukuoka, Japan.

Tawie, S. (2016). Retrieved 7 August 2019. https://www.malaymail.com/news/malaysia/2016/09/06/works-ministry-peat-soil-raising-cost-of-sarawaks-pan-borneo-highway/1200093.

Terashi, M., & Tanka, H. (1981). Proceedings from the Fifth International Conference on Soil Mechanics and Foundation Engineering: *Ground Improvement by Deep Mixing Method.* Paris: Dunod.

Terashi, M. (1997). Proceeding from the 14th International Conference on Soil Mechanics and Foundation Engineering: *Theme Lecture: Deep Mixing Method- Brief State of the Art.* Rotterdam: Balkema.

Termaat, R. J. (1994). Stress – Strain and Strength Behaviour. In D. Hann et al. (Ed.), *Advances in the Understanding and Modelling the Mechanical Behaviour of Peat* (pp 311-326). Rotterdam: Balkema.

The Malaysian Reserve. (2019). Retrieved 4 August 2019 https://themalaysianreserve.com/2017/04/03/md-closing-klia2-will-not-settle-soil-issues/.

Tingle, J. S., & Santoni, R. L. (2003). Proceedings from the Eighth International Conference on Low-Volume Roads: *Stabilization of Clay Soils with Nontraditional Additives*. Pennsylvania, USA: Transportation Research Board.

Tong, T. I., & Ling, N. L. (2015). Characteristics and correlation of the index properties peat soil: Parit Nipah. *Journal of Applied Science and Agriculture,* 10(5): 19–23.

Topolnicki, M. (2004). Proceedings from the Institution of Civil Engineers - Ground Improvement: *In Situ Soil Mixing*. U.K: Thomas Telford.

Veisi, M., Chittoori, B., Celaya, M., Nazarian, S., Puppala, A. J., & Solis, C. (2010). *Accelerated Stabilization Design of Subgrade Soils Research Report 0-5569-1. (2010), 79968 February 2010.* Center for Transportation Infrastructure Systems, the University of Texas at El Paso: El Paso.

Wetlands International. (2010). *A Quick Scan of Peatlands in Malaysia.* Wetlands International Malaysia: Petaling Jaya, Malaysia.

Wickham, D., & Hartley, M. (2012). *Formaldehyde: Report Abstract. Nexant's ChemSystems Process Evaluation/Research Planning (PERP) Program*. Nexant Inc.: San Francisco.

Wilson, D. (2011). *Humanitarian Charter and Minimum Standards in Disaster Response*. Geneva, Switzerland: The Sphere Project.

Wong, L. S., Hashim, R., & Ali, F. (2008a). Behaviour of stabilized peat soils in unconfined compression test. *American Journal of Engineering and Applied Sciences,* 2008(4): 274-279.

Wong, L. S., Hashim, R., & Ali, F. (2008b). Strength and permeability of stabilized peat soil. *Journal of Applied Science,* 2008(21): 3986-3990.

World Business Council for Sustainable Development 2009 – Carbon Emission Reductions up to 2050. (2010). International Energy Agency, Cement Technology Roadmap 2009. IEA Publications: Paris.

World Disaster Report (WDR) 2015: Focus on Local Actors, The Key to Humanitarian Effectiveness. IFRC Societies: Geneva, Switzerland.

World Disaster Report (WDR) 2016: Resilience: Saving Lives Today, Investing for Tomorrow. IFRC Societies: Geneva, Switzerland.

World Disaster Report (WDR) 2018: Leaving No One Behind. IFRC Societies: Geneva, Switzerland.

World Food Program (WFP): Annual Report. (2004). Communications Division World Food Programme: Rome, Italy.

Yardim, C. H. (2013). *A Study of Settlement of Stone Columns by Finite Element Modeling Through Case Histories*. (Doctoral dissertation). Middle East Technical University.

Yin, J. H., & Fang, Z. (2010). Physical modeling of a footing on soft soil ground with deep cement mixed soil columns under vertical loading. *Marine Georesources and Geotechnology,* 28(2): 173-188.

Yulindasari, I. (2006). *Compressibility Characteristics of Fibrous Peat Soil.* (Master dissertation). Universiti Teknologi Malaysia, Malaysia.

Yusof, A. (2019). Retrieved 8 August 2019 https://www.nst.com.my/business/2019/03/472656/klia-expansion-may-be-delayed-until-2023.

Yusoff, S. A. N. M., Bakar, I., Wijeyesekera, D. C., Zainorabidin, A., & Madun, A. (2014). Proceedings from International Integrated Engineering Summit (IIES 2014): *Comparison of Geotechnical Properties of Laterite, Kaolin and Peat.* Batu Pahat: UTHM.

Zainorabidin, A, & Bakar I. (2003). Proceedings from 2nd International Conference on Advances in Soft Soil Engineering and Technology: *Engineering Properties of in-situ and Modified Hemic Peat Soil in Western Johore*. Putrajaya, Malaysia.

Zainorabidin, A., & Mohamad, H. M. (2017). Engineering properties of integrated tropical peat soil in Malaysia. *Electronic Journal of Geotechnical Engineering,* 2017(22.02): 457-466.

Zainorabidin, A., & Wijeyesekera, D. C. (2007). Proceedings from Advances in Computing and Technology: *Geotechnical Challenges with Malaysian Peat.* Landon: UEL. http://doi.org/10.1016/j.jada.2010.08.016.

Zainorabidin, A., & Wijeyesekera, D. C. (2008). Proceedings from the Advances in Computing and Technology 3rd Annual Conference: *Geotechnical Characteristics of Peat*. Liverpool: Liverpool John Moores University.

Zdravkovic, L., Potts, D. M., & Hight, D. W. (2002). The effect of anisotropy on the behaviour of embankments on soft ground. *Géotechnique,* 52(6): 447-457.

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LIST OF PUBLICATIONS

Daud, M. N. M., Daud, N. N. N. (2018). *Effect of wet and dry conditions of MUF polymers on strength properties of treated peat soil. Lecture Notes in Civil Engineering in GCEC 2017* (pp. 1235-1246). Switzerland: Springer International Publishing AG.

Daud NNN, Daud MNM. (2015). Characterization of peat soil treated with polymer resin by unconfined compressive strength test. *Journal of Advanced Civil Engineering Practice and Research*. Ababil Publisher. 1(1): 11-17.

Daud MNM, Daud NNN. (2019). Compressibility Characteristic of peat soil treated with MUF-P resin. Original manuscript submitted to *International Journal of Engineering & Technology*, on 5th December 2018. Paper ID: DSTC-031

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