UNDRAINED SHEAR STRENGTH OF SOFT CLAY REINFORCED WITH SINGLE NON-ENCAPSULATED BOTTOM ASH MIXED WITH SILICA FUME COLUMN (BASF)

TAN KAH YEE

B. ENG (HONS.) CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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(Student's Signature)

Full Name : TAN KAH YEE

ID Number : AA15132

Date : 31 MAY 2019

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ABSTRAK

Tanah liat lembut adalah tanah yang bermasalah yang menyebabkan kegagalan kapasiti galaas dan penyelesaian yang berlebihan, yang mengakibatkan bangunan yang teruk dan kerosakan tapak. Oleh itu, peningkatan tanah diperkenalkan untuk meningkatkan sifat kejuruteraan tanah liat yang lembut. Dalam kajian ini, abu bawah digunakan untuk menggantikan agregat semulajadi manakala asap silika digunakan sebagai pengikat antara zarah abu bawah. Kajian ini adalah untuk menyiasat peranan abu bawah tidak terkandung tunggal yang bercampur dengan larutan asap silika (BASF) dalam meningkatkan kekuatan ricih kaolin dengan menggunakan model skala makmal. Kaolin digunakan sebagai sampel tanah manakala BASF sebagai lajur bertetulang. Ujian makmal dijalankan untuk menentukan sifat fizikal kaolin tanah liat, abu bawah, dan sampel silika asap. Ujian Mampatan Tidak Terkurung (UCT) juga digunakan untuk menguji kekuatan ricih sampel kaolin bertetulang. Sejumlah tujuh kelompok sampel kaolin telah diuji dan setiap kumpulan terdiri daripada lima spesimen mewakili sampel tanpa tiang BASF, penembusan sebahagian dan penembusan penuh untuk tiang BASF dengan diameter 50mm dan ketinggian 100mm. Diameter lajur bertetulang yang digunakan ialah 14mm dan 20mm dengan ketinggian 60mm, 80mm dan 100mm. Peningkatan kekuatan ricih BASF dengan nisbah penggantian kawasan 7.84% (diameter lajur 14mm) dan 16.00% (diameter lajur 20mm) adalah 58.97%, 88.56%, 69.81%, dan 19.19%, 38.73%, 32.81% pada nisbah penetrasi sampel , H_c/H_s 0.6, 0.8 dan 1.0 masing-masing. Dapat disimpulkan bahawa kekuatan ricih tanah liat lembut dapat ditingkatkan dengan pemasangan abu bawah tunggal yang tidak dikombinasi bercampur dengan lajur asap silika. Walau bagaimanapun, peningkatan kekuatan ricih diameter 14mm meningkat lebih ketara berbanding diameter 20mm disebabkan oleh gangguan kecil yang berlaku kerana sedikit kaolin digerudi dan diambil dari sampel dan menggerakkan tegasan pengurung yang lebih tinggi dalam lajur.

ABSTRACT

Soft clay is problematic soil that causes bearing capacity failure and excessive settlement, leading to severe buildings and foundation damage. Therefore, soil improvement is introduced to improve the engineering properties of the soft clay. In this study, bottom ash is used to replace the natural aggregate while silica fume is used as binder between bottom ash particles. This research is to investigate the role of single non-encapsulated bottom ash mixed with silica fume column (BASF) in improving the shear strength of kaolin by using laboratory scale model. Kaolin is being used as soil sample while BASF as the reinforced column. Laboratory tests are conducted to determine the physical properties of kaolin clay, bottom ash, and silica fume sample. Unconfined Compression Test (UCT) also used to test the shear strength of the reinforced kaolin samples. A total seven batches of kaolin sample had been tested and each batch consists of five specimens represent sample without BASF column, partially penetration and fully penetration for BASF columns with 50mm in diameter and 100mm in height. The diameter of reinforced column being used are 14mm and 20mm with heights of 60mm, 80mm and 100mm. The improvement of shear strength of BASF with area replacement ratio of 7.84% (14mm column diameter) and 16.00% (20mm column diameter) are 58.97%, 88.56%, 69.81%, and 19.19%, 38.73%, 32.81% at sample penetration ratio, H_c/H_s of 0.6, 0.8 and 1.0 respectively. It can be concluded that the shear strength of soft clay could be improved by the installation of the single non-encapsulated bottom ash mixed with silica fume column. However, the improvement of shear strength of 14mm diameter was increased more significant compared to 20mm diameter due to the small disturbance occurred since a small amount of kaolin was drilled and taken out from the samples and mobilization of the higher confining stresses in the column.

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LIST OF SYMBOLS

$\rho_{d(max)}$	Maximum dry density
Δs_u	Undrained shear strength improvement
A_c	Area of bottom ash mixed with silica fume column
A_s	Area of kaolin clay sample
D_c	Diameter of bottom ash mixed with silica fume column
D_s	Diameter of kaolin clay sample
e	Void ratio
G_s	Specific gravity
H_c	Height of bottom ash mixed with silica fume column
H_s	Height of kaolin clay sample
I_P	Plastic index
q_u	Deviator stress
R^2	Correlation cohesion
s_u	Undrained shear strength
V_c	Volume of bottom ash mixed with silica fume column
V_s	Volume of kaolin clay sample
w	Moisture content
w_d	Dry Soil
W_L	Liquid limit
w_{opt}	Optimum moisture content
W_P	Plastic limit
W_S	Shrinkage limit
w_w	Wet Soil
γ	Unit weight
γ_d	Dry unit weight
ρ_d	Dry density

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
BA	Bottom Ash
BASF	Bottom Ash with Silica Fume
BS	British Standard
CL	Low Plasticity Clay
LOI	Loss of Ignition
MCPP	Milwaukee County Power Plant
OCPP	Oak Creek Power Plant
OCXP	Oak Creek Expansion Units
PIPP	Presque Isle Power Plant
PPPP	Pleasant Prairie Power Plant
S	Single Non-Encapsulated Bottom Ash Column
SE	Single Encapsulated Bottom Ash Column
SEM	Scanning Electron Microscope
SM-MH	Medium Plasticity Silty Sand
SW	Poor Graded Sand
UCT	Unconfined Compression Test
USCS	Unified Soil Classification System
VAPP	Valley Power Plant

CHAPTER 1

INTRODUCTION

1.1 Background of Research

According to Al-Rawas and Qamaruddin (1998), Nuhfer said that losses are within $6 billion and $11 billion in defects to infrastructure and other infrastructure constructed over clay soil in United State every year. Besides that, sum of damage due to clay soil between Year 1977 and Year 1987 rise above $300 million in Arab Saudi. Clay soil swells when saturated with water and shrinks when water content falls. The swelling and shrinkage phenomenon affected by clay minerals, water content, dry density, soil formation, loading or weather. The city of Al-Khod has experienced urbanization. The constructions include Sultan Qaboos University, residential areas and other facilities. All the buildings were built based on the standard practice. The clay soil behaviours were not neglected due to the lack of past experience in design engineer and eventually causing evacuation of residents due to severe cracking.

Based on the Figure 1.1, the soft clay soils distribution in Malaysia is shown. There is 20% of the ground in the coastal area of Peninsular Malaysia is soft clay. Soft clay is natural material mainly consists of the flaky particles of mica, various types of clay minerals and organic matters. It composes of tiny particles which are plastically and adhesively. Clay tends to expand and shrink due to the voids which help to store water. Moreover, clay is high compressibility and low permeability which lead to the settlement. When water moisture content high, clay tends to soften and liquefy. The project in Malaysia which involves of clay soil is the embankment region during the East Coast Expressway. The typical very soft clay silts liquefy and have undrained shear strengths between 8-11kPa and depths of 8m (Aljanabi *et al.*, 2013).

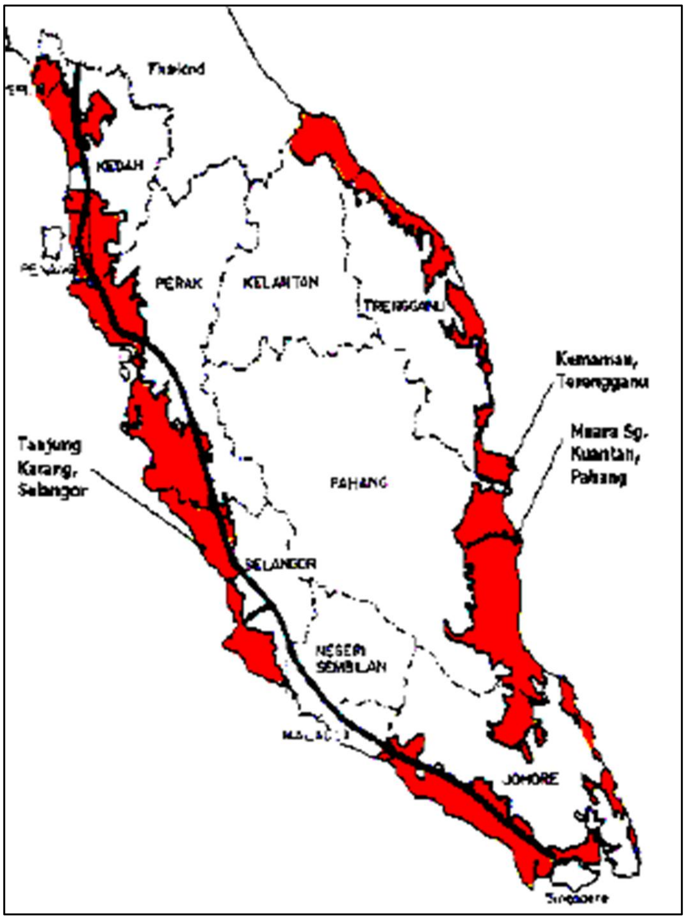

Figure 1.1 Malaysia soft clay soils distribution map

Source: Mohd Yusof *et al.* (2006)

Stability and settlement of a structure or a building is always influenced by the soil type existed at the ground. Historical construction over barren ground such as soft clay may lead to fail in bearing capacity and severe settlement due to its low shear strength and highly compressible. In geotechnical engineering, potential failure to the foundation and cracking of road pavement are also the results of construction over the weak soil. From Figure 1.2, there are three types of settlements which are uniform settlement, tipping settlement which often without cracks and differential settlement with cracks.

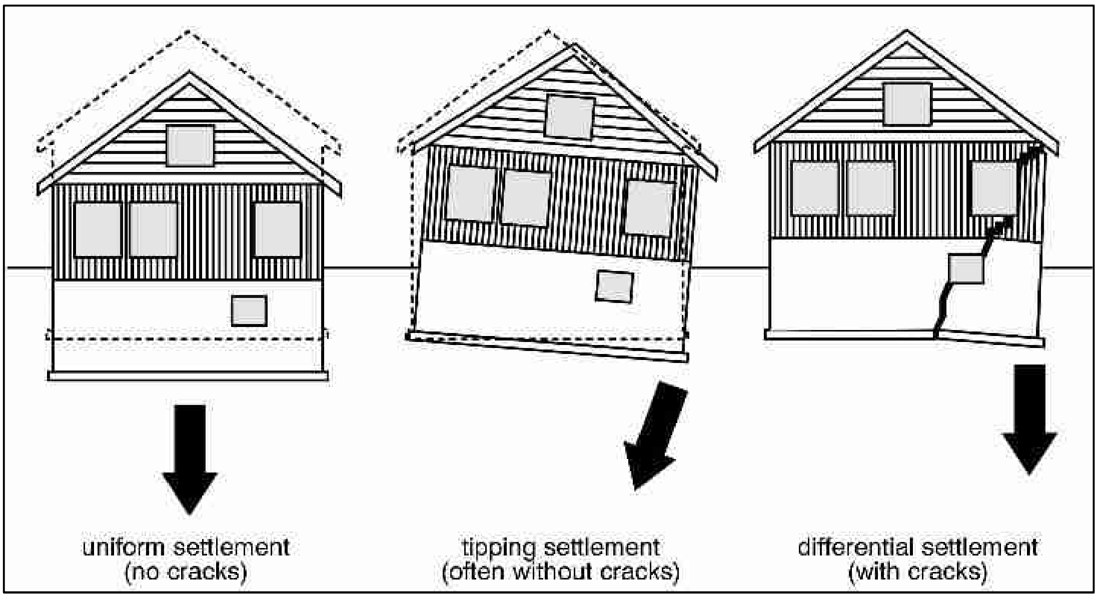

Figure 1.2 Types of settlement

Source: Khaled (2014)

Therefore, few ground improvement mechanisms are introduced to advance the soft clay mechanical and physical properties like preloading sand drains, vibrated granular columns, stone columns and alternative (Suki, 2015). There are a lot of suggestions to improve and modify the ground. For example, densification, dewatering and adding of admixture have invented and practiced century ago. Today, deep soil mixing (DSM) technology is widely practiced on a stimulating concept of improving remarkably natural soils to properly match adopted design requirements. Therefore, problematic excavation can be eliminated and expensive deep foundations methods can be replaced while producing a safe and economic ground engineering solution.

Deep soil mixing (DSM) technology is a sustainable technology as it uses non-toxic binders or industrial by-products as soil admixture. Concurrently, this technology also minimizes spoil volumes compare to jet grouting or classical drilled piles. The selected waste materials are bottom ash (BA) and silica fume. They are a by-product from the electric power plants. These waste materials are disposed and ordinarily possesses no economic value. Bottom ash is rough, porous, glazed, angular, grey in colour and inflammable residual gathered from the bottom part furnaces of burned coal whereas silica fume is extremely fine powder, spherical, grey to off-white in colour, high pozzolanic properties and acts as the filler in cementitious applications.

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