A STUDY OF TH[illegible]GTH OF SOFT CLAY REINFORCED WITH 6MM AND 8MM DIAMETER GROUP OF FOUR BOTTOM ASH COLUMN

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ABSTRACT

Soft clay that consists of low shear strength, low permeability and high compressibility characteristics will affect the stability and settlement of structures. Vertical granular column is one of the ground improvement techniques to improve strength of the soft soil. Bottom ash, as a residue of combustion of coal from coal power plants, has similar properties with sand. The weak soft soil is not suitable for structure construction. Hence, ground improvement is necessary to modify soil properties and increase shear strength of soft soil. Bottom ash is the by-product produced from the coal burning in power plant. The substantial amount of bottom ash disposed in the landfills generates serious environment pollution from time to time. Hence, by using bottom ash as granular material in vertical granular column, the cost of construction is reduced and this could be one of the methods in achieving sustainable development in construction industry. The aim of this Final Year Project is to determine the improvement in the shear strength of soft clay after being reinforced with a group of four bottom ash columns. The first stage of study was to determine the physical and mechanical properties of the materials used, which were kaolin and bottom ash. The results shows that kaolin can be classified as clayey soil whereas for the bottom ash it has relatively similar characteristics to sand. At the second stage, remoulded samples of 50mm in diameter and 100mm in height soft kaolin clay with undrained shear strength were reinforced with group of bottom ash columns and subsequently tested under Unconfined Compression Test. The diameter of bottom ash column is 6mm and 8mm, and the heights of column are 24mm, 36mm, 48mm and 68mm. The group columns have been arranged in square pattern. It can be concluded that the shear strength parameters were affected by the diameter and the height of the column. It can be concluded that the shear strength of soft clay could be improved by the installation of bottom ash columns. The presence of bottom ash column greatly improved the shear strength.

ABSTRAK

Tanah liat lembut yang mempunyai ciri-ciri kekuatan ricih yang rendah, kebolehtelapan rendah dan kebolehmampatan yang tinggi akan menjejaskan kestabilan dan enapan bangunan. Tiang tegak butiran adalah salah satu teknik pembaikan tanah untuk meningkatkan kekuatan tanah lembut. Abu dasar, sebagai sisa pembakaran arang batu dari loji janakuasa arang batu, mempunyai sifat-sifat yang serupa seperti pasir. Tujuan Projek Sarjana Muda ini adalah untuk menentukan peningkatan dalam kekuatan ricih tanah liat lembut selepas diperkukuh oleh satu dan sekumpulan tiang abu dasar. Peringkat pertama kajian adalah menentukan sifat fizikal dan mekanikal bahan-bahan yang digunakan iaitu kaolin (mewakili tanah liat lembut) dan abu dasar. Hasil kajian menunjukkan bahawa kaolin boleh diklasifikasikan sebagai tanah lempung manakala bagi abu dasar, ianya mempunyai ciri-ciri yang serupa dengan pasir. Pada peringkat kedua, 50mm diameter dan 100mm tinggi dengan sampel kaolin lembut telah diperkukuh dengan sekumpulan tiang abu dasar, dan kemudiannya diuji dengan Ujian Mampatan Tak Terkurung. Diameter sekumpulan empat tiang abu dasar 6mm dan 8mm , dan ketinggian tiang abu dasar ialah 24mm 36mm, 48 mm dan 68mm. sekumpulan tiang dasar telah dijadikan bentuk empat segi. Kehadiran tiang abu dasar dapat menambah kekuatan ricih dengan baik.

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LIST OF SYMBOLS

A_c	-	Area of Bottom Ash Column
A_s	-	Area of Sample
C_c	-	Coefficient of Curvature
C_c	-	Coefficient Uniformity
D_c	-	Diameter of Bottom Ash Column
H_c	-	Height of Bottom Ash Column
H_s	-	Height of Sample
c	-	Cohesion
G_s	-	Specific Gravity
kN	-	Kilo Newton
kPa	-	Kilo Pascal
Mg	-	Mega Gram
MN	-	Mega Newton
m/s	-	Metre per Second
mm	-	Milimetre
μm	-	Micrometre
q_{max}	-	Maximum deviator stress
s_u	-	Undrained Shear Strength
w	-	Moisture Content
w_{opt}	-	Optimum Moisture Content
p_d	-	Dry Density
$p_{d(\mathrm{max})}$	-	Maximum Dry Density
ϕ	-	Internal Friction Angle

LIST OF ABBREVIATIONS

ACAA	American Coal Ash Association
ASSHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
BA	Bottom Ash
BS	British Standard
LL	Liquid Limit
PI	Plastic Index
PL	Plastic Limit
SL	Shrinkage Limit
UCT	Unconfined Compression Test
US	United States
USCS	Unified Soil Classification System

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In the recent years, the government has been significantly developing the country by building vast amount of housing, commercial, industrial, and other infrastructure facilities. The development of urban cities is increasing rapidly around the world nowadays. The extensive growth of urbanization and industrialization become more significant, owing to the tremendous increase of population. Variety of structure had been constructed almost everywhere, including site which have low strength of soil layers, due to the limiting availability of appropriate sites. However, due to the limited availability of construction sites, prices of lands keep on increasing. The developers take the initiative to construct structure on the marginal sites which are considered more economic. Hence, ground improvement and modification technique is highly needed in order to solve the soft soil problem.

Constructing structure on poor ground such as soft clay will affect the stability and settlement of the structure. The soft clay consists of flow low shear strength, low permeability and high compressibility characteristics. Ground improvement may be necessitated to modify the soil properties. There are several methods to improve the soft clay properties such as preloading, sand drains, piling, vibrated granular columns, stone column and sand column.

Various techniques had been used to improve the soft soil, for example reinforcement with geosynthetic, lime treatment, acceleration of pre-consolidation using pre-fabrication vertical drains, and the most popular method; stone or granular columns. This method is applied commonly for road embankments and railway area, lightly loaded foundation, and storage tanks (Murugesan and Rajagopal, 2010).

Recently, stone columns are gaining acceptances in geotechnical field since the construction is simple and easy, economical in terms of material used and not bringing significant effect to the environment.

Vertical granular column is a process of digging vertical hole on the soft clay and filling the hole with granular materials to improve strength of the soft soil. This is one of the commonly applied ground improvement techniques. In general, vertical granular columns are either constructed as fully penetrating through a clayey soil layer overlying a firm stratum or partially penetrating with their tips embedded within the clayey soil layer (Shahu and Reddy, 2011).

Generally, stone or granular column is constructed either by replacement method for high groundwater level, or displacement method for low groundwater level. A vertical cylindrical hole is dug in soft soil layer and filled with compacted stone or gravel, as shown in Figure 1.1. The hole is usually being dug to bedrock or hard layer and rarely into some meter deep (Poorooshasb and Meyerhof, 1997).

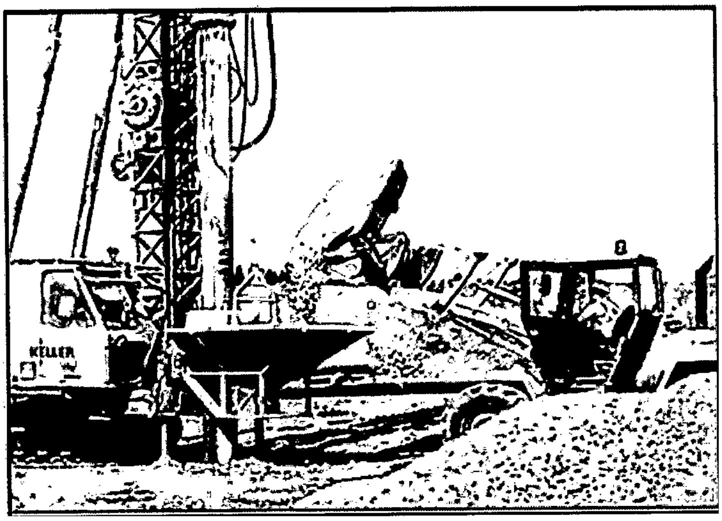

Figure 1.1: Installation of stone column
(Source: McCabe *et al.*, 2007)

Previous studies have proven that the vertical granular column technique such as stone column has been successfully applied to increase the shear strength of soft soil and to decrease the settlement for structure foundation (Ambily and Ghandi, 2007). Stone columns act as piles that transfer the structure load to greater depth. Hence, this explains why granular materials in the vertical granular columns increase the soft soil shear strength and stiffness.

Bottom ash is the residue of combustion of coal from coal power plants, which is collected from the bottom of furnaces. The physical properties of bottom ash are porous, coarse, granular, grayish and glassy. In Peninsular Malaysia, there are four coal power plants which are Tanjung Bin, Jimah, Kapar, and Manjung. Specifically for Tanjung Bin Power plant alone, it has produced 180 ton/day of bottom ash and 1620 ton/day of fly ash from 18000 ton/day of coal burning (Muhardi, 2010).

Currently, the recycling and fully utilization of waste materials have attracted great attention in construction field to fulfil the current interest in long term and sustainable development, as well as to reduce the cost of managing the landfill. According to Kumar and Stewart (2003) the properties of bottom ash and sand are almost similar. Hence, the bottom ash has unforeseen potential to be used to substitute sand in vertical granular column. This will reduce the costs of construction and on the other hand, landfill property can be reclaimed and put to profitable use.

1.2 Problem Statement

In today's construction industry, geotechnical engineers always challenged by the presence of weak strata that consist of soft soil, which is very complex material, problematic and has varies engineering characteristic. This has lead to the findings and applications of various types of ground improvement technique that being used nowadays, for example stone column.

Soft clay is a problematic clay soil since it has low bearing capacity, low permeability and high compressibility characteristics. The weak soft soil is not suitable for structure construction. Hence, ground improvement is necessary to modify soil properties and increase shear strength of soft soil. Vertical granular column is one of the feasible and economic techniques that serve the purpose of soil strengthening. Bottom ash is the by-product produced from the coal burning in power plant. The substantial amount of bottom ash disposed in the storage generates serious environment pollution from time to time. The recycling and fully utilization of waste material have attracted great attention in construction field to fulfil the current interest in long term and sustainable development, as well as to reduce area if managing the storage. Previous studies show that the properties of bottom ash are similar to sand. Hence, by using bottom ash as granular material in vertical granular column, the cost of construction is reduced and this could be one of the methods in achieving sustainable development in construction industry.

Coal fired power plant in the production of electricity produced solid waste, referred to coal ash. The solid waste is pulverized fuel ash, bottom ash, boiler slag, and flue gas desulfurization material. Coal is dividing in four categorized in relation to its carbon content, volatile substance, and heating value such as anthracite, bituminous, and lignite.

Even though there is no report about the producing of coal ash annually in Malaysia, but basically there is about 10 per cent of total weight of the coal burned produces ash (Huang, 1990). In 2020, gas is the main resource fuel about 71% of the total generates power plants in Malaysia. However coal has been projected as a possible further fuel in the future with the total projected installed capacity on the coal power plant will be increase to 22.5 million tons for 8200 MW capacities in 2010. These huge quantities of coal ash storage space, and hence increase the expenses to obtain large areas. Besides that, it will be a social and environmental problem as the result of magnification of disposal areas and the increase disposal expenses will be finally transferred to end users. Ash disposal also may pose an environmental hazard.

In other perspective, the use of a huge amount of coal has resulting the waste issues, when the ashes containing unburned coal and slag are being disposed off in a large landfill or mined out area (Sathonsaowaphak , 2009). Therefore, it is necessary to recycle the coal burning wastes instead of dispose them in order to save money as well as to keep the environment safe. Therefore, this study relates both two problems stated above, where the bottom ash was reused to replace stone or sand in columns for ground improvement technique.

Thus, by studying the engineering characteristics of bottom ash taken from Tanjung Bin Power Plant, the characteristics of bottom ash can be analyse. From literature studies, it is observed that there is limited investigation on coal ash in Malaysia although a lot of studies have been made worldwide. It is also thought that there should be a database on the characteristics of local coal ash so that result that systematically recorded could be extracted and used by others. Hence, it will encourage other researchers to use the results for further investigation on the application of the material in civil engineering and construction industry.

The results form researcher by Huang (1990) on bottom ash showed that the engineering properties most bottom as are more favorable than those traditional highway material and has a capability to improve asphalt pavement performance when used to substitute a portion of the aggregate in asphalt mixes. Hence, it is the time to start a systematics investigation of the physical, chemical and mechanical properties of coal ash, in particular the bottom ash. Research work on engineering characteristics of bottom ash from Tanjung Bin power plant will be carried out and results obtain. The results analysis will hopefully can help the civil engineers to maximize and explore the usage of coal bottom ash in civil engineering works since the characteristics of this ash are well established.

1.3 Objective of Study

The objective of study is aim to investigate the improvement of undrained shear strength of soft clay reinforced of bottom ash column.

i. To determine the physical characteristics of kaolin clay of bottom ash, and morphological characteristic of bottom ash.
ii. To determine the effective shear strength parameter of soft clay reinforce with various dimension of group bottom ash column through Mohr-Coulomb failure criterion.
iii. To establish correlations relating the undrained shear strength parameter with various dimension of group bottom ash column installed in soft clay.

1.4 Scope of Study

This study was conducted based on specific scope in order to ensure the specified scope of the study area. It is also implemented in order to achieve the objective of the study.

i. The physical of kaolin, we determined from the following laboratory test:
   a) Liquid Limit and Plastic Limit Test
   b) Specific Gravity Test
   c) Standard Compaction Test
   d) Falling Head Permeability Test
   e) Hydrometer Test

ii. The physical properties of bottom ash, were determined from the following laboratory tests:
   a) Specific Gravity Test
   b) Dry Sieve Test

c) Direct Shear Test
d) Constant Head Permeability Test
e) Standard Compaction Test
f) Relative Density Test

The undrained shear strength parameter of soft clay reinforce with various dimension of group of three bottom ash columns, had been determined from Unconfined Consolidated Test with the following step. To produce repeatable homogenous soft clay sample, kaolin powder had been at is easy to obtain. Every batch of kaolin sample was produced by using compaction method. Diameter and height of each sample was 50 mm and 100 mm respectively. Meanwhile, the diameters of group column were 6 mm and 8 mm.

1.5 Significance of Study

In this study, the purpose is to determine the improvement shear strength of soft clay after reinforced with a group of bottom ash column. Thus, there are some experimental procedures carried out to evaluate the suitability of bottom ash in replacing sand in sand column. By utilizing bottom ash as granular material in sand column, problems of disposing huge amount of bottom ash in the landfills can be solved. In addition, the bearing capacity of soft soil is increased and settlement of structure foundation is reduced. Without question, this would increase significantly the availability of marginal sites for cheaper and long-term construction.

This study aimed at determining the improvement made by the installation of bottom ash columns to the shear strength of soft soil in laboratory scale model. Some laboratory tests were carried out to investigate whether the bottom ash is suitable to replace the stone or sand in columns for ground improvement technique.

By the completion of this study, two problems were solved with one solution. The use bottom ash columns for ground improvement technique was not only increased bearing capacity of soft soil but also had reduced the waste problem of bottom ash which currently was disposed totally in large quantity into landfill. Besides, it was expected that the use of bottom ash to replace sand or stone in columns can save a lot of money since the coal bottom ash is a waste from coal combustion, compared to the expensive sand or stone.

In this modern era of developing country, it is really necessary to have some efforts to recycle or reuse things to not only save costs but also keep the environment safe so that it can last long for the next generation. This study was hopefully being a part of the efforts to help our country developing comfortably.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

According to Head (1992), soils mechanics in that branch of engineering science that applies the principles of mechanics, hydraulics and geology to the solution of engineering problems in soils. It is one aspect of the earth science known as geotechnics, or geotechnology, which also encompasses rock mechanics, geophysics, hydrology and engineering geology.

The study of soil mechanics covers the investigation, description, classification, testing and analysis of soils to determine their inter-reaction with structures built in or upon them or with them.

2.2 Soft Clay

According to the Unified Soil Classification System (USCS), clays are fine-grained soils which have more than 50 % by weight passing No.200 US Standard sieve (0.075 mm). Clays consist of clay minerals of ultramicroscopic size, mostly quartz and feldspar. In usual engineering practice, clays are designated as the friction smaller than

2 μm (0.002 mm). 'Very soft' clay is the soil having the unconfined compressive strength of less than 25 kPa, whereas 'soft' clay has the shear strength between 25 to 50 kPa (Brand and Brenner, 1981).

2.2.1 Basic Index Properties

The index parameter is a measure of the behaviour and physical properties of a soil, which are mostly used for soil identification, classification and description. They are generally governed by the amount of clay friction, the mineralogical composition, the structure of the gains, distribution of the gains and the gains texture. The primary clay mineral are; kaolinite, halloysite, illite, montmorillonite and chlorite (Kempfert and Gebreselassie, 2006).

Tan (2004) had done an investigation on the geotechnical properties of soft marine clay at Bukit Tinggi, Klang. From their reults shown in Figure 2.1, they concluded that the subsoil was normally soft, inorganic, possess medium to extremely high plasticity, and compressible with high liquidity index.

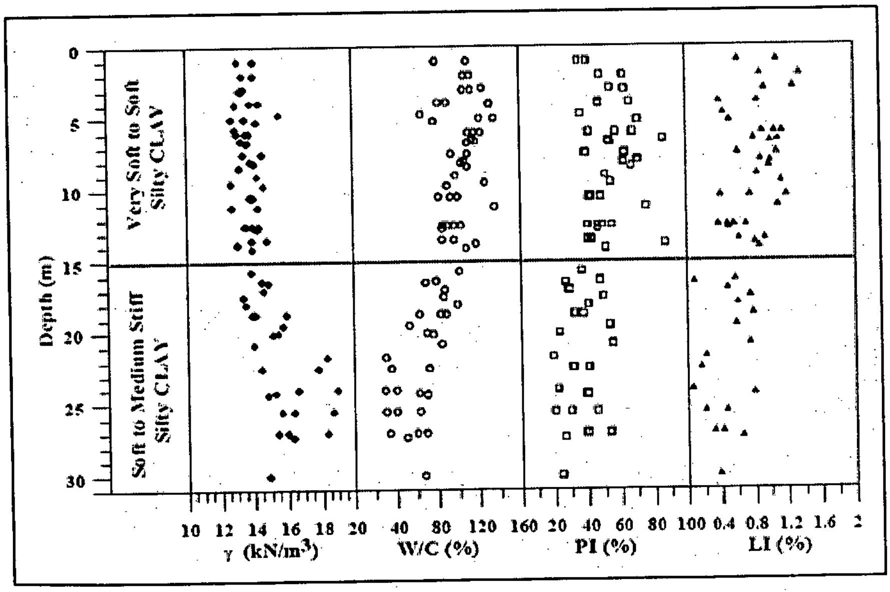

Figure 2.1: Basic properties of upper and lower Klang clay
(Source: Tan, 2004)

Jamal (1997) in their study about the undrained shear strength, s_u of soft clay at Bukit Raja, Klang found the following results. The average value of plastic limit was 38 % (in the range of 30 % to 45 %), the average liquid limit was 85 % (in the range of 75 % to 95 %), the average moisture content was 86 % (in the range of 74 % to 97 %), the average specific gravity was 2.6 (in the range of 2.5 to 2.7) and finally the average unit weight was 14.45 kN/m^3 (in the range of 13.8 kN/m^3 to 15.1 kN/m^3).

2.2.2 Compression Properties

In consolidation process, soil particles are packed more closely over a period of time under continuous pressure, resulting in drainage of water from pore spaces between the particles. The main parameter required the compressibility of the soil, known as coefficient of volume compressibility. It is a measure of the amount by which the soil will compress when loaded and allowed to consolidate (Head, 1992).

Azhar (2004) in his study about the engineering characteristics of soft clay in Peninsular Malaysia reported that the value of compressibility index obtained was in the range of 0.09 to 1.39, the coefficient of consolidation was between 1.24 to 8.72 m^2/year and the coefficient of volume compressibility was in the range of 0.056 to 2.084 m^2/MN. He concluded that the compressibility index had increased with natural moisture content, Atterberg limit and void ratio.

2.2.3 Shear Strength Properties

Shear strength refers to the soil's ability to resist sliding along internal surfaces within a mass of the soil. Shear strength, s of a soil may be expressed by the Coulomb equation (Liu and Evett, 2005) :

$$s = c + \sigma \tan \phi \qquad (2.1)$$

Cohesion, *c* refers to strength resulted from the ionic bond between grain particles. The angle of friction, ϕ refers to the strength gained from internal frictional resistance (rolling and sliding) offered by interlocking action among soil particles. Whereas σ is the effective intergranular normal pressure (Liu and Evett, 2005).

In 2004, Tan in their study summarized that the undrained shear strength, s_u of Klang clay was in range of 18 kPa to 50 kPa. Jamal (1997) in their study used four different approaches to determine the undrained shear strength, s_u of the soft clay at Bukit Raja, Klang. From their result shown in Figure 2.2, they concluded that the value of s_u was low (in the range of about 6 kPa to 23 kPa) and was categorized as very soft clay.

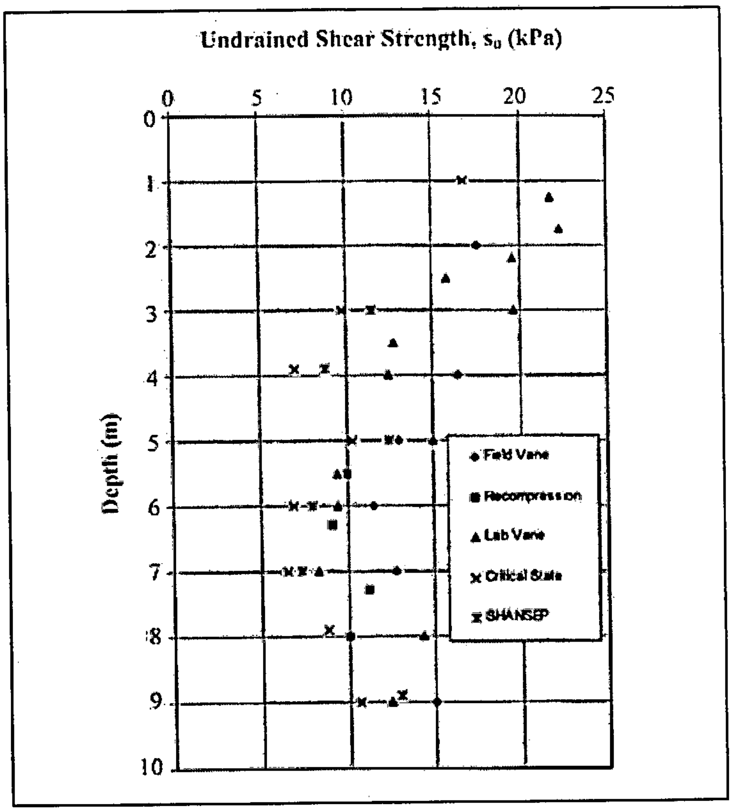

Figure 2.2: Detemination of undrained shear strength using various methods

(Source: Jamal, 1997)