STUDY OF THE STRENGTH OF SOFT CLAY REINFORCED WITH SINGLE ENCAPSULATED BOTTOM ASH COLUMNS

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ABSTRAK

Tiang batu adalah salah satu teknik pembaikan tanah yang mesra dengan alam sekitar yang berkesan kos dan berdaya maju untuk mengurangkan penyelesaian asas di atas tanah lembut yang padu. Pemasangan tiang batu boleh meningkatkan keupayaan galas dan rintangan ricih jisim tanah. Abu bawah adalah sisa pembakaran arang batu umumnya adalah kasar, berbutir dalam bahan bentuk yang digunakan sebagai tiang batu dan ia mungkin mengurangkan penggunaan bahan yang tidak boleh diperbaharui seperti batu dan pasir. Selain itu, dengan memperkenalkan ruangan abu bawah, kemampanan boleh dicapai dan masalah pelupusan untuk abu bawah boleh diselesaikan. Kertas kerja ini membincangkan hasil kekuatan tanah liat lembut diperkukuhkan dengan terkandung tiang abu bawah tunggal. Sebanyak enam (6) kumpulan sampel kaolin telah diuji untuk menentukan kekuatan ricih. Setiap kumpulan terdiri daripada tiga (3) sampel untuk mewakili saiz yang berbeza ketinggian tiang abu bawah. Sebanyak 18 ujian terkukuh tak tersalir tiga paksi telah dijalankan ke atas spesimen kaolin lembut. Spesimen telah digunakan dalam projek ini adalah 38 mm garis pusat dan 76 mm tinggi. Garis pusat tiang abu bawah adalah 6 mm dan 8 mm dan ketinggian tiang adalah 38 mm, 57 mm dan 76 mm. Untuk garis pusat tiang abu bawah 6 mm, nilai parameter kekuatan tanah liat lembut dimasukkan dengan 38 mm ketinggian ruangan meningkat lebih ketara berbanding dengan ruang menembusi sepenuhnya iaitu 76 mm tinggi daripada tiang-tiang. Garis pusat tiang abu bawah 8 mm, nilai parameter kekuatan tanah liat lembut dimasukkan dengan menembusi sepenuhnya ruangan yang 76 mm tinggi meningkat lebih ketara berbanding dengan 38 mm pada ketinggian tiang.

ABSTRACT

Stone column is one of the ground improvement techniques that are environmental friendly with effective cost and viable to reduce settlement of foundations on cohesive soft soil. Installation of stone column can increase the bearing capacity and the shear resistance of the soil mass. Bottom ash is the waste of coal burning generally is a coarse, granular in shape material that is used as stone columns and it is probably reducing usage of non-renewable material such as stone and sand. Besides that, by introducing bottom ash columns, sustainability can be achieved and the disposal problem for bottom ash can be solved. This paper discusses the results of the strength of soft clay reinforced with single encapsulated bottom ash columns. A total of six (6) batches of kaolin samples had been tested to determine the shear strength. Each batch consisted of three (3) samples to represent different size of height of bottom ash columns. A total of 18 unconsolidated- undrained triaxial tests had been conducted on soft kaolin specimens. The specimens were used in this project is 38 mm in diameter and 76 mm in height. The diameter of the bottom ash columns is 6 mm and 8 mm and the heights of the column are 38 mm, 57 mm and 76 mm. For diameter of the bottom ash columns 6 mm, the value of strength parameters of soft clay inserted with 38 mm height of the columns increased more significant compared to the fully penetrating column which is 76 mm in height of the columns. The diameter of the bottom ash columns 8 mm, the value of strength parameters of soft clay inserted with fully penetrating column which is 76 mm in height increased more significant compared to the 38 mm in height of column.

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A_c	-	Area of Bottom Ash Column
A_s	-	Area of Sample
C_c	-	Coefficient of Curvature
C_u	-	Coefficient of 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	-	Meter per Second
mm	-	Millimeter
µm	-	Micrometer
q_{max}	-	Maximum deviator stress
s_u	-	Undrained Shear Strength
w	-	Moisture Content
w_{opt}	-	Optimum Moisture Content
ρ_d	-	Dry Density
$\rho_{d(max)}$	-	Maximum Dry Density
ϕ	-	Internal Friction Angle

LIST OF ABBREVIATIONS

ACAA	American Coal Ash Association
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
BA	Bottom Ash
BS	British Standard
LL	Liquid Limit
PL	Plastic Limit
PL	Plastic Limit
SL	Shirinkage Limit
UU	Unconsolidated Undrained Test
US	United States
USCS	Unified Soil Classification System

CHAPTER 1

INTRODUCTION

1.1 Background

In engineering practice, sustainability does not stop at the development of new and environmental friendly materials for construction purposes, but also the reutilization of materials that were erstwhile considered as waste by products of industrial processes. During the last few decades, bottom ash is a waste material that has seen a transformation to the status of by products and more recently products that are sought to construction and other application (Tharaniyil *et al.*, 2004). In order to neglect the negative impact to the earth, people have become more aware of the uncontrollable use of non-renewable natural material.

People start to realize how to protect the earth by reducing the cost of a construction project as well as reduce the disposal area, there is a better solution by using bottom ash as substitute material in stone column. The properties of bottom ash are similarly to sand. Bottom ash is one type of the solid residues by products produced from coal and it is used to replace fine aggregate (sand). Bottom ash is the waste of coal burning use as stone columns and it is probably reducing usage of non-renewable material such as stone and sand.

According to Mahmud (2003), in Malaysia alone, coal-burning power plants have generated more than 15.5 million tons of coal in 2007 and the valued had been predicted to increase up to 22.5 million tons in 2010 as coal-burning power plant is the main source of energy in this country. Coal is one of the world's important sources of energy thus it is being used extensively by power generation plant that existed due to the chemical of materials. According to Joseph (2005), with the two or more new constructed coal-fired power plants, Jimah and Tanjung Bin, coal consumption is expected to increase from 10 million tons to 19 million tons in year 2010. The burning of coal produces coal ash that mostly consists of 80% of fly ash and 20% of bottom ash and it is produced at coal power plant.

Based on Figure 1.1, there are some examples coal-fired power plant located in Malaysia. But the biggest coal-fired power plant in South-East Asia is at Tanjung Bin, Pontian, Johor which is owned by Malakoff Corporation Berhad. Tanjung Bin Power Plant is the first private coal-fired plant in Malaysia was constructed completely in schedule within 48 months and 16 days to make it one of the largest infrastructure projects in South-East Asia. The power plant has a generating capacity of 2,100 MW (700MW x 3 Units) and boasts the largest boiler drums in the world, with more than 21,000 welds per boiler which passed three hydrostatic tests without a single failure.

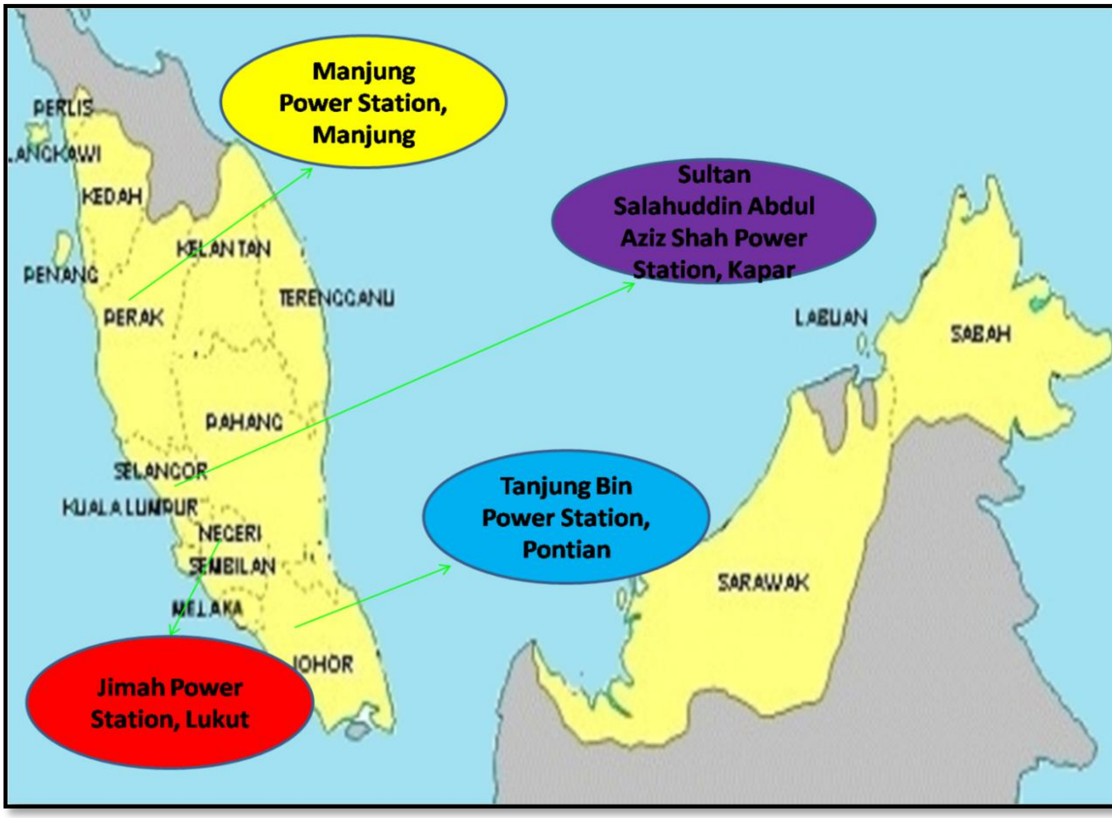

Figure 1.1: Coal-fired power plants in Malaysia (Mahmud, 2003)

Due to develop country to compete economically with others, there is one most commonly method used for ground improvement to stabilize the soil called stone column. Since the properties of bottom ash are almost similar to sand (Kumar and Stewart, 2003), there is a good potential of using this bottom ash as substitute material in stone column. Stone column are designed to improve bearing capacity and it is consists of compacted gravel or crushed stone. The columns are used to increase the strength, decrease the compressibility of soft and loose fine graded soils and accelerate a consolidation effects (Pivarc, 1976).

Day by day, the solid waste is produced and it cause pollution to our environment. In order to protect our environment on this earth, stone column is preferable to replace concrete material for foundation since stone column is made from natural materials. To improve properties of ground improvement, soft clay soil is required. Marto *et al*. (2013) have stated that there are many available methods to improve the properties of soft clay soil such as sand drain, piling, stone column, using admixtures and many more. Each stone column is assumed to be surrounded by an equivalent area of soil.

There are some other benefit can expected by using stone column in term of quality such as sustainability in construction. Many researchers have developed theoretical solutions for estimating the bearing capacity and settlement of foundations reinforced with stone columns (Priebe, 1995). Stone column usually installed in soft cohesive soil and been successfully reduce the settlements of the constructions.

1.2 Problem Statement

In engineering studies, structure is the most important courses and really meant to stand firm in the world because structure have to provide great strength to support loads. Recently, foundation settlements are the biggest problems occur in building constructions caused by weak compaction of soils. Many residential buildings have high risk construction failure due to the soft soil. When the conditions of the soil are weak, then the potential to the strength of soil becomes weaker is highest. So, there is high probability the structures was not safe to use because the structures have high tendency to fail.

Soft clay is the major part of soft soil that has low bearing capacity and high compressibility. Soft clay soils are characterized by low shear strength and are highly plastic fine grained soils with moderate to high clay fraction. Due to the failure occur for the building construction, many researcher finds out that by using soft clay, settlements of the foundation cannot be solve completely. Furthermore, soft clay have a high moisture content because soft clay have the lowest of permeability where water are hard to get through it particles. In fact, the soils become more unstable caused by the presence of water.

By the weak conditions of the soil, the stiffness of the soil could easily be affected and this has made the soil become weak in strength. However, the economically technique of ground improvement is to increase the bearing capacity of the soil hence reducing the settlements of the soft soil. Soft clay soil then mixed with coal ash produced by Tanjung Bin Power Plant and by coal-burning it is produced fly ash and bottom ash. Fly ash has been commercialized and it is used to substitute into the cement.

As the consumption of coal by power plants increases, so does the production of coal by product such as bottom ash. While the use of coal increases, waste issues associated with coal production is more thoughtfulness. Malaysia has a great record on the environmental issues caused by human behavior. To greenly our earth, waste material is being used such as bottom ash. Bottom ash is used as substitute in the stone column because stone column is one of the methods of ground improvement to improve the properties of the soil.

On the other hand, last production of bottom ash as alternative measures to replace natural sand in stone column. Therefore, bottom ash has potential construction utilization because bottom ash can produced from unitary source that can be entirely difference depending on the operating conditions and procedures. Looking on the brighter side of things, there is an alternative way of optimizing the usage of coal waste material based into value added product in construction industry.

1.3 Objective

The purpose of this project is to study the strength of soft clay reinforced with encapsulated bottom ash columns.
The main objectives of this study are:

i. To determine basic and mechanical properties of soft clay and bottom ash.
ii. To determine the strength of soft clay reinforced with encapsulated single bottom ash column.

1.4 Scope of Study

Based on discussion with my supervisor, this project focused on the strength parameter of soft clay reinforced with encapsulated bottom ash column. The experiments were run and analyzed in the Soil Mechanic and Geotechnical Laboratory Faculty of Civil Engineering and Earth Resources (FKASA), Universiti Malaysia Pahang (UMP). Bottom ash for this study had been collected from Tanjung Bin Power Plant in Johor, Malaysia. All the laboratory experiments were performed with kaolin Grade S300. The laboratory experiments were carried out using the kaolin specimen in cylindrical with the diameter 38 mm and the height is 76 mm. Then, the diameter of the bottom ash is 6 mm and 8 mm with height 38 mm, 57 mm and 76 mm.

i. The tests were conducted for physical properties of kaolin are:

    a) Atterberg Limit Test
    b) Standard Proctor Compaction Test

c) Hydrometer Test
d) Falling Head Permeability Test
e) Specific Gravity Test

ii. The tests were conducted for physical properties of bottom ash are:

a) Standard Proctor Compaction Test
b) Sieve Analysis Test
c) Direct Shear Test
d) Constant Head Permeability Test
e) Specific Gravity Test
f) Relative Density Test

The shear strength parameter of soft clay reinforced with encapsulated bottom ash columns had been determined from Unconsolidated Undrained Test with the following steps:

a) Every batch of kaolin sample was produced by using compaction method.
b) Diameter and height of each samples was 38 mm and 76 mm respectively.
c) The columns were installed at the centre of the specimens and each sample represents samples with partially penetrating column and sample with fully penetrating column.
d) The diameters of single encapsulated column were 6 mm and 8 mm. The effective confining pressure which is consists of 50 kPa, 100 kPa and 200 kPa.

1.5 Research Significance

High risk faced by engineers when continue construct a building on the soft clay soil. After all, a very detail soil investigation need to be done because of soft clay has high compressibility and low bearing capacity that caused failure to engineering design and structure. By using ground improvement method, stone column can improve the shear strength of soft soil and increasing the bearing capacity. In fact, the total settlements can be reduced and structure for building construction successfully be achieved. Stone column helps reducing the large amount presence of water in the soft clay soils and water can be easily get through it particles. Then the soft clay soils has high strength and in a strong condition.

In shorts, recycle waste materials can saved the earth and reduce the pollutions thereby making clean and humans can breathe well. By using the bottom ash as replacing aggregate in stone column, it will be economical since it is waste materials that produced from coal burning. Bottom ash is environmental friendly in construction industry so that it can be used in proper way as stated before. Bottom ash can solve the disposal problem since it cannot be disposed everywhere but only in landfill. In addition, it is also can reduce the cost of construction project hence it will helps construction industry to growth on the world stage.

In other words, bottom ash is being used in stone column as an alternative for ground improvement method that is economic friendly and viable. Hence, this method can improve the shear strength of soft clay soils and avoid failure for construction building. This method also increasing the bearing capacity and reducing the settlements that could affects the movement of the whole structures. Besides that, the soil particles have low tendency to bond closely with one another while doing the compaction thus the soils becomes strong in strength and can support high load.

CHAPTER 2

LITERATURE REVIEW

2.1 Ground Improvement

Ground improvement techniques can improve the soil engineering properties in order to support the foundation or structures. Most of the techniques contribute great opportunity in geotechnical engineering such as increase in shear strength, the reduction of soil compressibility, influencing permeability to reduce and control ground water flow or to increase the rate of consolidation, or to improve soil homogeneity (Kirch & Moseley, 2005). Therefore, ground improvement is a very important study in geotechnical engineering to avoid failure in construction such as settlement of foundation, soil expansion due to excessive moisture which can cause cracking in the foundation, walls, ceilings, patios, sidewalks, driveways, or retaining walls and could also cause soil movement or also known as landslide to happen. Based on study done by Sokolovich (1988), application of chemical method to stabilize organic clay is sufficiently reliable to modify the soil properties by means of some solid or liquid additive and in many cases it is the only possible measure for strengthening weak soil.

2.2 Stone Column

One of the ground improvement techniques that are environmentally friendly with effective cost and viable to reduce settlement of foundations on cohesive soft soil is the installation of stone column. Stone columns provide an economical method of support in compressible and cohesive soils for low-rise buildings, lightly loaded foundations, earth structures and storage tanks that can tolerate appreciable movement, (Mitchell *et al.*, 1991). By increasing the shear resistance of the soil mass and its bearing capacity, columns are installed in weak soil as reinforcements that are made of compacted aggregate. Furthermore, installation of the stone column can reduce liquefaction potential of cohesionless material under seismic loading and to stabilize slopes and embankments provides a shorter drainage pathway for the native soil resulting in an increase in the rate of consolidation and acceleration of the settlement.

McCabe *et al*. (2009) stated that the behavior of stone columns has yet to be captured fully by analytical and numerical techniques. Hughes and Withers (1974) and Balaam and Booker (1981) utilized the concept of unit cell to predict the capacity of single stone column, which assumes that each column in the group has a tributary domain of the surrounding soil. There is no shear stress or lateral deformation on the outside of the boundaries because the domain has a cylindrical shape with a rigid exterior wall. Mostly, single stone column fails by bulging and a group of stone columns together with the surrounding soil may fail by general, local, or punching shear mechanism (Ayadat, 2014).

A lower-bound solution of the composite cell model was developed to estimate the capacity of a group of stone columns (Bouassida *et al.*, 1995). A method to estimate the amount of settlement for end-bearing stone columns was developed (Priebe, 1995). Priebe (2005) proposed a similar method for floating stone columns. Ellouze *et al*. (2010) criticized the Pribe method for being inferior to other simple design methods for analyzing stone column foundations. The homogenization method by Lee and Pande