UNDRAINED SHEAR STRENGTH OF SOFT CLAY REINFORCED WITH 8MM AND 16MM DIAMETER A GROUP OF BOTTOM ASH COLUMN

NURHAMIZAH BINTI ZAINAL ABIDIN

Report submitted in fulfillment of the requirement
for the award of the degree of
B. Eng (Hons) CIVIL ENGINEERING

Faculty of Civil Engineering & Earth Resources
UNIVERSITI MALAYSIA PAHANG

JULY 2014

ABSTRACT

A variety of structures had been constructed almost anywhere, including site which have lower strength of soil layer. Recently stone column has gained acceptance in the geotechnical field since the structure is simple and easy, economical in material used and not bringing significant effect to environment. Bottom ash, as a residue of coal's combustion from coal power plants, has similar properties with sand and there is a potential to use as stone columns. The utilization of the industrial by-products is recognized nowadays due to the continuous dwindling of non-renewable natural materials. Furthermore, the large production of bottom ash from coal burning in Malaysia has results in waste issues. So, by using bottom ash columns, the disposal problem for bottom ash could extensively be reduced. It is necessary to reuse and recycle this material because environmentally friendly and avoid to use of natural and non-renewable resource such as gravel and sand as a replacement in the column using laboratory scale model. The aim of this Final Year Project is to show the improvement level in shear strength of soft clay after being reinforced with group bottom ash columns. The first phase of this study is to determine the physical properties of the material used which is kaolin as soft clay and bottom ash as reinforcing column. In the second phase of study, consolidated kaolin with was reinforced by group of bottom ash column and tested for the shear strength using Unconfined Compression Test. The dimension of the soft clay sample is 50 mm in diameter and 100 mm in height. In this study, five samples of soft clay were fixed. For each sample was installed with group bottom ash column with various in height and size. For the column, the diameter used are 8 mm with height 32 mm, 48 mm, and 64 mm, and for 16 mm diameter, the height of column are and 64 mm, 96 mm, and 100 mm. The highest increment in shear strength was 59.23 % from control sample for 8 mm diameter column. Meanwhile for 16 mm diameter column the increment was about 13.29 % compare to control sample.The installation of bottom ash column as reinforcements had increased the shear strength of the soft clay and the degree of improvement was influenced by the column penetration ration as well as the area replacement ratio.

ABSTRAK

Pelbagai jenis struktur bangunan telah dibina di mana sahaja , termasuk tapak yang mana mempunyai kekuatan lapisan tanah yang lemah. Kebelakangan ini tiang batu telah mendapat penerimaan di bidang geoteknikal kerana strukturnya yang mudah dan senang, ekonomi pada bahan yang digunakan dan tidak membawa kesan sampingan kepada persekitaran. Abu dasar , merupakan adalah sisa buangan dari pembakaran batu arang dari kilang-kilang tenaga arang, dan mempunyai ciri-ciri yang sama dengan pasir dan mempunyai potensi untuk digunakan sebagai tiang batu. Penggunaan produk sampingan perindustrian dikenali sekarang ini disebabkan kekurangan bahan asli tidak boleh diperbaharui. Tambahan pula, pengeluaran besar abu dasar dari pembakaran arang batu di Malaysia mengakibatkan penghasilan isu sisa. Jadi, dengan menggunakan dasar tiang-tiang abu, masalah pelupusan untuk abu dasar boleh dengan meluas dikurangkanIa perlu digunakan semula dan kitar semula bahan ini kerana mesra alam dan untuk mengelakkan penggunaan sumber tidak boleh dibaharui dan semula jadi seperti kelikir dan pasir sebagai satu gantian di lajur menggunakan skala makmal model. Tujuan Project Sarjana Muda ini ialah untuk menunjukkan tahap peningkatan kekuatan ricih tanah liat lembut selepas diperkuat dengan kumpulan tiang abu dasar. Fasa pertama kajian ini ialah untuk menentukan sifat fizikal bahan yang digunakan dimana kaolin sebagai tanah liat lembut dan abu dasar sebagai tiang pengukukuhan. Di fasa kedua kajian, kaolin dengan diperkukuhkan oleh kumpulan tiang abu dasar dan diuji untuk kekuatan ricih menggunakan kaedah Ujikaji Mampatan Tak Terkurung (UCT). Dimensi sampel tanah liat lembut ialah 50 mm garis pusat dan 100 mm tinggi. Dalam kajian ini, lima sampel tanah liat lembut telah ditetapkan. Untuk setiap sampel telah dipasang dengan kumpulan tiang abu dasar dengan pelbagai ketinggian dan saiz. Untuk TIANG abu dasar, garis pusat digunakan ialah 8 mm dengan ketinggian 32 mm, 48 mm , dan 64 mm , dan untuk 16 mm garis pusat, ketinggian tiang ialah 64 mm, 96 mm , dan 100 mm. Penambahan kekuatan ricih yang paling tinggi ialah 59.23 % berbanding dengan sampel kawalan untuk 8 mm garis pusat tiang. Sementara itu untuk 16 mm garis pusat tiang peningkatan kekuatan ricih adalah lebih kurang 13.29 % berbandingan sampel kawalan. Pemasangan ting abu dasar sebagai pengukuhan telah menambah kekuatan ricih tanah liat lembut dan darjah peningkatan dipengaruhi oleh nisabah penembusan lajur serta nisbah penggantian kawasan.

TABLE OF CONTENT

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A_c	Area of bottom ash column
A_s	Area of kaolin sample
D_c	Diameter of bottom ash column
G_s	Specific gravity
H_c	Height of bottom ash column
H_s	Height of sample
kN	Kilo Newton
kPa	Kilo Pascal
Mg	Mega Gram
MN	Mega Newton
m/s	Metre per second
mm	Millimeter
μm	Micometer
q	Deviator stress
q_{max}	Maximum Deviator Stress
s	Shear strength
s_u	Undrained shear strength
V_c	Volume of bottom ash column
V_s	Volume of kaolin sample
w	Moisture content
w_{opt}	Optimum moisture content
ρ_d	Dry density
$\rho_{d(max)}$	Maximum dry density
γ	Unit Weight

γ_{max}	Maximum unit weight
ϕ	Friction angle
%	Percent
°	Degree

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ACAA	Americans Coal Ash Society for Testing and Materials
ASTM	American Society
BA	Bottom Ash
BS	British Standards
CCP	Coal Combustion Product
LL	Liquid Limit
PI	Plasticity Index
PL	Plastic Limit
UCT	Unconfined Compression Test
USCS	United Soil Classification System

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Stability of civil engineering structures depends on the soil properties such as shear strength, permeability, and compressibility of the soil. The low potency of nature soil such as clayey soil could cause the excess settlement and failure on the civil engineering structure. Therefore cracking on main structure or pavement could happen if the structure such as road, embankment, and dam were constructed along the lower strength of soil. This can increase a high cost to restore or repair the engineering structures.

Therefore several methods are introduced to stabilize the soil in order to improve the characteristic of soil such as compressive strength, compressibility and permeability of the soil. For example reinforcement with geosynthetic, acceleration of pre consolidation using vertical drain, lime stabilization and the most popular recently is stone or granular column. This method particularly applied for the road embankment and railway area and storage tank (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. Stone column is opening up a vertical cylindrical hole in soft clay subsequently filling it up with compacted aggregate or stone. The hole is usually being dug to bedrock or hard layer and rarely into some meter deep (Dash and Bora, 2013).

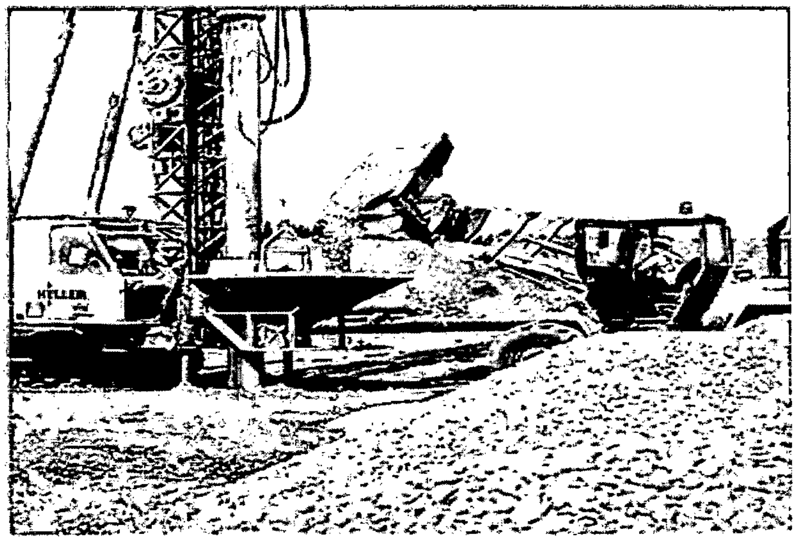

Figure 1.1: Installation of stone column (McCabe *et al.*, 2007)

Previous study and application on projects had proven that the installation of stone columns had successfully and effectively improves bearing capacity of weak and soft soil, reduces the post-construction settlement of the structure built and reduction in total settlement, reduces the liquefaction potential of clean sands, improves the stability of embankments and natural slopes, and accelerates the consolidation process (Dash and Bora, 2013). The columns act as piles that transmitting the structure load to greater depth, where the material used will provide a greater shear strength and higher stiffness of the composite soil mass. Moreover, the columns act as vertical drains which reduce the path length for the dissipation of excess pore water pressure that generated during loading. Thus, the consolidation process will be faster (Maakaroun *et al.*, 2009).

Nowadays Malaysia promotes coal as an option for fuel in electric power generation. Coal is a secondary important energy source after gas in Malaysia. In year 2010, about 40% of electric power in Malaysia will generated by coal-fired power plant compared to year 1999 and year 2003 with about 8% and 25% respectively (Energy Commission Malaysia, 2005). Increasing of electricity demand has led to increase the coal consumption and thus significantly produced more coal waste products.

Bottom Ash is a solid combustion residue produced during coal burning. The physical properties of bottom ash are basically similar to natural sand, with particle size

Both of fly ash and bottom ash is disposed as waste materials. Landfill has been the primary method of disposal of these waste materials. The problems that occur to disposal this coal ash are limited availability of land and very costly since large volume of coal ash is generated. Besides that, the coal ash presents a significant environmental problem to the surrounding area. This significant volume of material that need to be handle economically and in way that reduces the impact on the surrounding environment. However, this environmental problem can be minimized by reducing the need for ash landfills.

Recycling a large volume of coal combustion product in geotechnical application such as road embankment, fill material etc. may offer an attractive alternative. This method can achieve the sustainable development by replace the coal combustion product with uncontrollable usage of non-renewable natural material such as sand gravel (Hasan *et al.*, 2011)

However, from literature studies, it is observed that there is limited investigation on coal ash in Malaysia. Although there are a lots of studied related to the properties of coal ash, but the investigation about the local coal ash is very limited. Therefore, it is necessary to provide the information based on the laboratory evaluation of the locally available coal ash.

1.3 RESEARCH OBJECTIVES

This study intends to determine the improvement of shear strength of soil reinforced with encapsulated bottom ash column. Hence, there are the following objectives to be achievable

1. To determine the physical characteristic of soft clay and bottom ash
2. To identify the undrained shear strength of soft clay reinforced with encapsulated group bottom ash column
3. To correlate the relationship of undrained shear strength with various dimensions of group of bottom ash column installed in soft clay.

1.4 SCOPE OF STUDY

The materials that used in this study are the kaolin type S300 as sample soil and bottom ash as reinforced column. The dimension of the soft clay sample is 50mm x 100mm. To determine the physical properties of kaolin and bottom ash, the following laboratory test was carried out:

Table 1.1: Laboratory test for material

Material	Kaolin S300	Bottom ash
Laboratory test	i. Atterberg Limit ii. Hydrometer test iii. Standard Compaction Test iv. Falling Head Permeability Test v. Sieve Analysis vi. Specific Gravity Test	i. Dry Sieve Test ii. Standard Compaction Test iii. Constant Head Permeability Test iv. Specific Gravity Test v. Direct Shear Test

Next, consolidated soft clay with was reinforced by of bottom ash column and tested for the shear strength using Unconfined Compression Test. The dimension of the soft clay sample is 50mm x 100mm. In this study, four samples of soft clay were fixed. For each sample was installed with group bottom ash column with various in height and size. For the column the diameter used are 8mm, and 16 mm. So, the area ratio of the between the area of the bottom ash column and area of the specimen (A_c/A_s) are 7.68%, and 30.72%. The heights of bottom ash column are 32mm, 48mm, and 64mm for diameter column and 64mm, 96mm, and 100mm for 16mm diameter column. So the penetration ratios between the heights of column with the height of the specimen (H_c/H_s) are 0.32, 0.48 and 0.64, 0.96 and 1.0 respectively.

1.5 SIGNIFICANCE OF STUDY

This study aim to determine the improvement made by the installation of the bottom ash column to the shear strength of soft soil in the laboratory scale model. Some laboratory tests are carrying out to investigate whether the bottom ash is suitable to replace the stone or sand in column for ground improvement technique. By the completion of this study, 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 SOFT CLAY

Soft clays are formed by the geological weathering of the earth's surface. The rock stone that make up the earth's crust erode to microscopic particles to form clays. Yusof *et al.* (2006) state that soft clay can be describe as a soft earth, which is plastic, or be molded with the hands. Based on Unified Soil Classification System (USCS), clay is fine grained soils that have more than 50% by weight passing No.200 US Standard sieve (0.075 mm). It consists of clay minerals of ultramicroscopic size.

According to McCarthy, (2007) clay soil has particle sizes less than about 0.005mm. Soft clay soil cannot be separated by sieve analysis test because the particles are too fine where no practical sieve can be made with the openings so small. Instead, the soil can be tested and determined by observing settling velocities of the particles in a water mixture. Soft clay soil is also subjected to be plasticity high when mixed with optimum amount of water

2.1.1 Basic Index Properties

Yusof *et al.* (2010) review the properties of soils are not only related to the soil types, but also with the grain arrangement and natural moisture content of the soils which are very important. The basic index properties of a soil sample include the amount of particle soils, ratio of dry mass particles to the saturated mass particle, soil classification and natural moisture content. This study also agreed by Muhardi *et al.* (2010) in their study about the basic index of properties of soft clay.

Tan *et al.* (2004) had done an investigation on the geotechnical properties of soft marine clay at Bukit Tinggi, Klang. Based on the results, it was concluded that the subsoil was normally soft, inorganic, possess medium to extremely high plasticity, and compressible with high liquidity index. Meanwhile Yusof *et al.* (2006) had conduct on test engineering properties of soft clay at two places. First the test had been done at RECESS Research Center Johor and at Kg. Mat Lagam, Terengganu. Soil at both this place can be categorized as clay with small percentage of fine sand and large percentage of silt and clay.

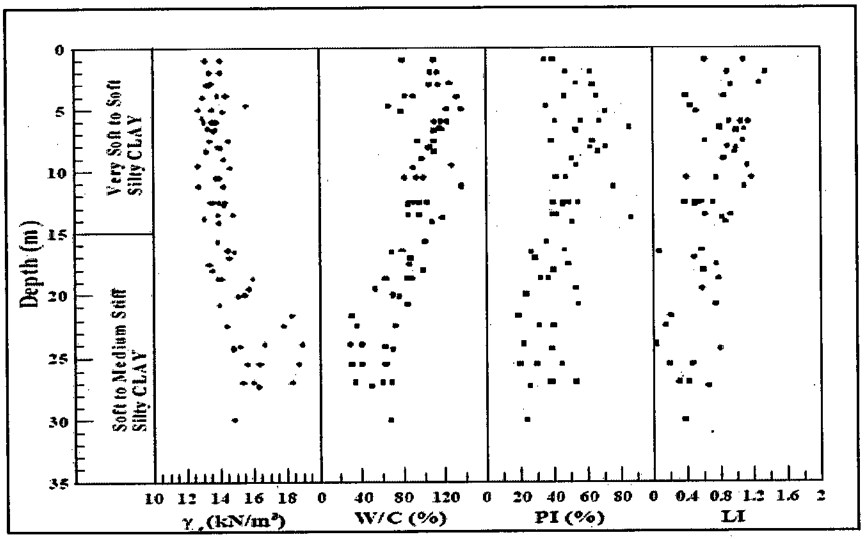

Figure 2.1: Basic properties of soft clay (Tan *et al.*, 2004).

Jamal, (1997) found the undrained shear strength, s_u of soft clay at Bukit Raja, Klang. The results were displayed as 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 lastly the average unit weight was 14.45 kN/m^3 (in the range of 13.8 kN/m3 to 15.1 kN/m3).

2.1.2 Compression Properties

Soil particle is more closely packed in the consolidation process over a period of time under continuous pressure resulting in drainage of water from pore spaces between the particles. The main parameter required is 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).

Saiful *et al.* (2004) discussed about the engineering characteristic of soft clay reported that the value of compressibility index was in the range 0.09 to 1.36. Meanwhile the coefficient of consolidation was between 1.24 to 8.72 m^2/MN 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 increased with natural moisture content, Atterberg limit and void ratio.

2.1.3 Shear strength properties

Shear strength is a soil parameters essential for the analysis of embankment stability (total stress) and bearing capacity of foundation in saturated clay (Tan *et al.*, 2004). It also refers to the internal surfaces within a mass of the soil to resist sliding.

Tan *et al.* (2004) summarized that the undrained shear strength, s_u Klang clay was in the range 18 kPa to 50 kPa. From the results obtained, it was concluded that the soil categorized by soft clay to firm clay. From the past research by Jamal *et al.* (2003) found the value of undrained shear strength was low which is in the range 6 kPa to 23 kPa and was categorized as very soft clay.

2.2 BOTTOM ASH

Bottom ash is the one of the coal burning waste products. It consists of non-combustible granular material and removed from the bottom dry boilers. Raw bottom ash is much coarser than fly ash (Colonna *et al.*, 2012). The growing size of the bottom ash disposal areas has led to the idea of utilizing the waste into engineering applications.

It is important to study the mechanical and physical properties of the bottom ash. It includes investigating for example its specific gravity, particle size distribution, permeability, compressibility, compaction, and shear strength.

2.2.1 Specific Gravity

Specific gravity, G_s is defined as the ratio of the unit weight of given material to the unit weight of water (Das, 2010). As reported by some researcher in the previous study, the value of specific gravity of bottom ash is 1.99 which is low due to the low iron oxide contents. The value is very low compare to the natural soil with specific gravity in the range 2.5 – 2.7. Specific gravity is related to the chemical composition, the porosity and the shape of the bottom ash (Muhardi *et al.*, 2010).

Muhardi *et al.* (2010) conducted a study to investigate the engineering properties of Tanjung Bin coal ash. They found the specific gravity of dry bottom ash is 2.35 lies on range 2.0 – 2.96 and specific gravity of wet bottom ash is 2.75 in range 2.6 – 2.9. However, Marto *et al.* (2013) in their study obtained the specific gravity value of 2.44. In addition the value was significantly similar to research done by Hasan *et al.* (2011). The value is higher compare to Awang *et al.* (2011) which is in 2.19 – 2.36. Even with the same source, specific gravity of bottom ash is differing from day to day because due to its dense nature (Kim *et al.*, 2006)

2.2.2 Particle Size Distribution

Soil can be separated in terms of equivalent particle diameter into six categories which are called boulders, cobbles, gravel, sand, silt, and clay. Particle size analysis is done to determine the relative proportion by dry mass of each size range, whether they are nearly the same size, well – graded or poorly graded. According to Head (1992). Soil can be divided into six categories knows as boulder, cobbles gravel, sand, silt, and clay as shown in Table 2.1 below:

Table 2.1: Particle classification (Head, 1992)

Sample	Particle Sizes (mm)
Gravel	2 - 60
Sand	0.06 - 2
Silt	0.002 – 0.06
Clay	Smaller than 0.002
Fines	Passed sieve 0.063
Clay fraction	Smaller than 0.002 as determined by standard sedimentation procedure

Muhardi *et al.* (2010) in their conclude that the size distribution of bottom ash particles was well-graded which is ranging from fine gravel to fine sand between 20 mm to 0.075 mm and categorized as coarse grained materials according to BS5930. Their results were similar with Marto *et al.* (2013) which is the majority size of bottom ash in a range 14 mm and 0.065mm. Additionally, bottom ash fall in the A-1 group and classified as A-1-a according to ASSHTO system (Muhardi *et al.*, 2010).

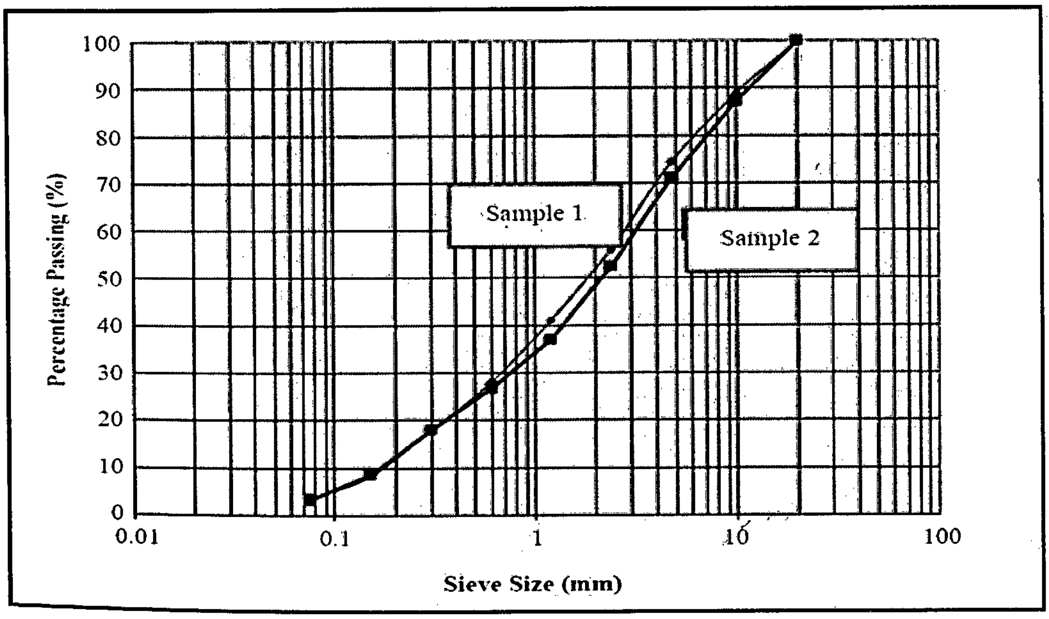

Figure 2.2: Particle Size Distribution of Bottom Ash (Muhardi *et al.*, 2010)