A STUDY OF THE [illegible] H OF SOFT CLAY REINFORCED WITH 10MM AND 16MM DIAMETER SINGLE ENCAPSULATED BOTTOM ASH COLUMN

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ABSTRACT

Stone column is one of the most commonly used in soil improvement technique around the world which capable to increase the bearing capacity of soft clay and able to reduce the settlement of superstructure constructed on them. Due to its higher value of strength and stiffness, it can sustain larger proportion of the applied load which improves the performance of foundation beds. Meanwhile, the substantial amount of bottom ash disposed in the landfills have causes a serious environment pollution. As the bottom ash is part of the residue of combustion of coal and also the by-product produced in a furnace of the power plant. Hence, by reutilize the bottom ash as granular material in vertical granular column, the cost of construction can be reduced and able to achieve more strength of soft clay after being reinforced with a single bottom ash column which been encased with geotextile. The first stage of the study was determine the physical and mechanical properties of the material used such as soft clay and bottom ash. The results shows that kaolin can be classified as silty soil while the properties of bottom ash has relatively similar characteristic with sand. At the second stage, remoulded specimens of 50mm in diameter and 100mm in height soft kaolin clay with single encapsulated bottom ash columns was subsequently tested under Unconfined Compression Test. The diameter of the encapsulated bottom ash column is 10mm and 16mm. It can be concluded that the shear strength parameters shows some significant improvement on encased and non-encased bottom ash columns and were affected by the diameter and height of the column.

ABSTRAK

Tiang batuan adalah merupakan salah satu yang teknik biasa digunakan dalam teknik pembaikan tanah di seluruh dunia yang mampu meningkatkan keupayaan galas tanah liat dan dapat mengurangkan pemendapan struktur dibina di atas struktur. Oleh kerana nilai yang lebih tinggi dapat disalurkan daripada kekuatan dan kekakuan, ia boleh mengekalkan sebahagian besar daripada beban kenaan yang dapat meningkatkan prestasi asas tersebut. Sementara itu, jumlah yang besar abu bawah yang dilupuskan di tapak pelupusan boleh menyebabkan pencemaran yang serius terhadap alam sekitar. Disebabkan abu bawah adalah sebahagian daripada sisa pembakaran arang batu dan juga produk yang dihasilkan dalam relau loji kuasa. Oleh itu, dengan menggunakan semula abu bawah sebagai bahan berbutir dalam tiang berbutir menegak, kos pembinaan dapat dikurangkan dan dapat meningkatkan lebih kekuatan daripada tanah liat lembut yang diperkukuhkan dengan tiang abu bawah yang tunggal yang diselaputi dengan geotekstil. Peringkat pertama dalam kajian ini adalah untuk menentukan sifat-sifat fizikal dan mekanikal bahan yang digunakan seperti tanah liat lembut dan juga abu bawah. Keputusan menunjukkan bahawa kaolin boleh diklasifikasikan sebagai tanah berkelodak manakala sifat abu bawah mempunyai ciri-ciri yang hampir sama dengan pasir. Pada peringkat kedua, spesimen berdiamter 50mm dan tingginya 100mm tanah liat kaolin lembut yang di perkukuhkan dengan tiang abu bawah tunggal yang diselaputi dengan geotextil kemudiannya diuji di bawah Ujian Mampatan Tak Terkurung. Garis pusat tiang abu bawah tersebut adalah 10mm dan 16mm. Ia boleh disimpulkan bahawa parameter kekuatan ricih menunjukkan peningkatan yang ketara pada bersalut dan tidak bersalut tiang tunggal abu bawah dan ia juga berubah berdasarkan diameter dan ketinggian turus.

TABLE OF CONTENT

TABLE NO.	TITLE	PAGE
2.1	Physical properties of Batu Pahat soft clay (Chan and Ibrahim, 2008; Robani and Chan, 2009; Ho and Chan, 2011)	9
2.2	Physical properties of bottom ash (Singh and Siddique, 2012)	13
2.3	Direct shear test results from previous researchers (Fadzil, 2011)	16
2.4	The effect of area replacement ratio on undrained shear strength of sand column (Suki, 2014)	21
2.5	Effect of spacing over diameter ratio on the ultimate load capacity (Ambily and Gandhi, 2007)	25
2.6	Properties of Geosynthetics (Kumar *et al.*, 2013)	26
2.7	Production of soft kaolin clay samples (Hasan *et al.*, 2011)	30
3.1	Summary of Laboratory Testing Programme	37
3.2	Sample with variable of bottom ash installation	48
4.1	Summary of kaolin clay properties	51
4.2	Summary of Tanjung Bin bottom ash properties	52
4.3	Summary of Polyster Non-Woven Geotextile Needlepunched properties	53
4.4	Comparison of bottom ash specific gravity values	56
4.5	Result of Unconfined Compression Test	63
4.6	Shear Strength Improvement	64
4.7	Maximum deviator stress and axial strain values at different area replacement ratio and different height penetration ratio for the singular encapsulated bottom ash columns	66
4.8	Correlation equation and cohesion value	87

LIST OF TABLE

LIST OF FIGURE

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	America n 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 Malaysia, rapid urbanisation and growth of infrastructure has dramatically increased the demand for the land space. Meanwhile, soft soils has created a challenge for the engineer especially towards the construction industry because of the characteristic of the soil usually characterized by a low permeability and shear strength together with a high compressibility and low bearing capacity. Due to these factors, the buildings that constructed on this type of soils pose a formidable challenge to the engineer. In general, there is little appreciation of the problems associated with construction of any building on the soft soil which causes a number of projects that have to be run into rough weather.

Most of the construction problems that occur are insufficient of bearing capacity, excessive post construction settlement and instability on excavation and embankment forming. So, a lot of ground improvement methods have been developed and used in many parts of the world to minimize these problems.

Constructing structure on poor ground such as soft clay will affect the stability and settlement of the structure. Ground improvement can considered in order to modify the soil properties. There are number of methods that can be used to improve the soft clay properties such as preloading, sand drains, piling, vibrated granular columns, stone column and sand column.

The initial design of foundation system introduced as a geotextile encased columns (GECs) which has been successfully adopted and is well established in engineering practice (Raithel and Kempfert, 2000; Raithel *et al.*, 2002). Similar concepts based on geogrid encasement as a more robust and perhaps stiffer alternative to geotextile have more recently been introduced and investigated (Sivakumar *et al.*, 2004) to demonstrate the effectiveness of geosynthetic encasement and to improve design methods.

Stone column is one of the most commonly used of soil improvement technique around the world which can increase the bearing capacity of soft soils and able to reduce the settlement of superstructures constructed on them. Due to its higher value of strength and stiffness, it can sustain larger proportion of the applied load which improves significant the performance foundation beds (Hughes *et al.*, 1974).

Bottom ash is produced as a result of burning coal in a dry bottom pulverized coal boiler. The unburned material was from a dry bottom boiler that consists of about 20 percent bottom ash. The basic properties of bottom ash are a porous, glassy and dark gray material with a grain size similar to the sand or gravelly sand (Steam, 1978). Although similar to natural fine aggregate, bottom ash is lighter and more brittle and has a greater resemblance to cement clinker (Rogbeck and Knutz, 1996). Bottom ash is taken at the bottom of the combustion chamber in a water-filled hopper and is removed by means of high-pressure water jets and conveyed by sluiceways to a decanting basin for dewatering, stockpiling, and possibly crushing (Steam, 1978).

The recycling and utilization of coal ash have attracted great attention in construction field to fulfil the current interest in long term and sustainable development in Europe, as well as to reduce the cost of managing the landfill. According to Kumar and Stewart (2003), the properties of sand and bottom ash are almost similar. Hence, the bottom ash has the potential to be used as a substitution to replace sand in the vertical granular column. It reduced the costs of construction and can be put to profitable use.

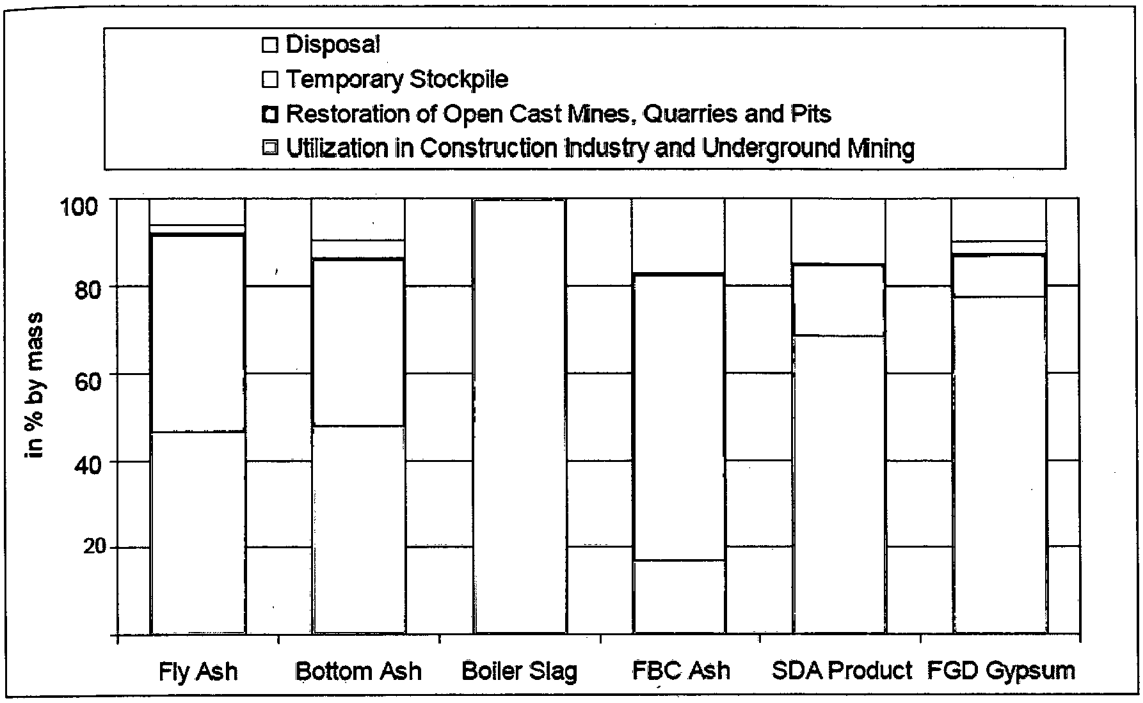

Figure 1.1: Utilization, temporary stockpile and disposal of Coal Ash in Europe in 2008 (WOCA, 2008)

1.2 PROBLEM STATEMENT

The scheduled industrial waste generations have been produces about 1,705,308 metric tonnes in Malaysia in the year 2009 (Malaysia Environment Quality Report. Department of Environment, Ministry of Natural Resources and Environment: Malaysia, 2009). Most of major components of the wastes are from, slag, dross, clinker, ash, gypsum, oil and hydrocarbon. All of the wastes must be properly disposed and managed without causing any harmful effects to the environment (Naganathan *et al.*, 2011). About 126,288 metric tonnes of industrial wastes was treated by *Kualiti Alam Sdn Bhd*, Malaysia. Around 25,000 tonnes of bottom ash (BA) have been produced and the incineration of these waste are sent to secured landfills but the disposal by land filling is not a very sustainable solution (Naganathan *et al.*, 2011). Various methods of using the bottom ash need to be developed and utilized in order to encourage the usage of bottom ash in the construction industry. If the incineration bottom ash reused, it ensured sustainability, reduce pollution, environmental degradation, and generate revenue, while preserving the natural virgin resources. (Sivakumar *et al.*, 2010).

The construction industry is now need to rethink the utilization of the industrial by-products as new supplementary materials because of the continuous usage and depletion of natural aggregates in construction (Abubakar and Baharudin, 2012). As we know the usage of non-renewable natural materials (NRNMs) including sand, gravel, crushed stone, slag, recycled concrete and geosynthetic aggregates depletes the reserve of the global's of minerals around the world as it is not a renewable energy. They are considered as non-renewable because they will run out one day. Burning fossil fuels generates greenhouse gases and relying on them for energy generation is unsustainable.

The replacement of sand with bottom ash waste reduces the usage on NRNMs while avoids the future bottom ash landfill area. Bottom Ash also classified under Scheduled Waste SW 104 (Environmental Quality Act) and by using this material, it is more environmentally friendly and sustainable thus avoids the use of natural resources such as sand and gravel (Ibrahim, 2012). Other advantages of using the bottom ash are can be substitute for raw materials for concrete block, paver brick, and light weight concrete and replace aggregate replacement in road construction.

Other than that, the existing soil on a given site may not be suitable for supporting the desired facilities such as buildings, bridges and dams because of the safe bearing capacity of a soil maybe not adequate to support the loading from the structure. In order to improve these soil types which allow building and other heavy construction, it is necessary to create stiff reinforcing elements in the soil mass. A number of these techniques have been developed in the last fifty years. The mechanics of ground improvement depends largely on the type of soil. A method to improve or increase of the strength is by incorporation of cylindrical inclusions or columns made of a material that have higher strength characteristics into a weak foundation soil, will result in an increase of its bearing capacity (Zahmatkesh and Choobbasti, 2010).

Soft clay is a problematic soil since it has low bearing capacity, low permeability and high compressibility characteristics. The weak soft soil is not suitable for structure construction. So, ground improvement is necessary to modify soil properties and increase shear strength of soft soil.

Considering for a soft clay with a relatively low shear strength, two kinds of column reinforcement techniques can be used which are the 'stone column' technique which consists in introducing within the soft clay a vibrocompacted stone or ballast material, the friction angle of which may exceed 40° and the 'lime column' technique obtained from mixing the weak soil mass with a given percentage of lime or lime–cement, thus producing a considerable increase of the soil initial shear strength (up to 20 times), together with a relatively small friction angle (Zahmatkesh and Choobbasti, 2010).

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 physical characteristics of kaolin and bottom ash.
ii) To determine undrained shear strength parameter of kaolin and the kaolin reinforced with various dimensions of single encapsulated bottom ash columns.
iii) To correlate properties of soft clay reinforced with single encapsulated bottom ash columns.

1.4 SIGNIFICANCE OF STUDY

In this study, the purpose is to determine the improvement shear strength of soft clay after reinforced with a singular of bottom ash column encased with geotextile. The experimental procedures carried out to evaluate the suitability of bottom ash in replacing stone in stone column. All the problems of disposing of the bottom ash in the landfills can be solved by replacing the bottom ash as granular material in stone column. Then, the bearing capacity of soft soil is increased and settlement of structure foundation is reduced. It would increase the availability of marginal sites for cheaper and long-term construction.

This study aimed to determining the improvement made by the installation of encapsulated bottom ash columns to the soft soil in small scale modelling. A series of 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.

After the completion of this study, the problems related with bottom ash were solved with one solution. The usage of bottom ash columns as ground improvement technique was able to increase bearing capacity of the soft soil but also had reduced the waste of bottom ash which currently disposed in large quantity into landfill. Besides that, the usage of bottom ash to replace stone in columns can be considered as economic and environmental friendly since the coal bottom ash is a waste from coal combustion, compared to the expensive stone.

1.5 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 reinforced with various dimensions of single encapsulated bottom ash columns, had been determined from Unconfined Compression Test with the following step:

i) Every batch of kaolin sample was produced by using compaction method.
ii) Diameter and height of each sample was 50mm and 100mm respectively.
iii) The diameters of single encapsulated column were 10mm and 16mm. The effective confining pressure which is consists of 25kPa, 50kPa and 100kPa of effective confining pressure.

CHAPTER 2

LITERATURE REVIEW

2.1 SOFT CLAY

Most of the areas in Malaysia have soft clay soil as the major soil distribution percentage. In fact that most of the Malaysia has many parts of coastal areas and also consists of rivers that located in many states in peninsular Malaysia (Sa'adon, 2009). Fine grained saturated soils were believed to be located at most of the near coastal and river area (Schaefer, 1997).

The soft clay can be categorized as CH (Inorganic Clays of High Plasticity) based on the index properties of the soil, according to the Unified Soil Classification System (Robani and Chan, 2009; Chan and Ibrahim, 2008). It is also highly plastic fine grained soils with moderate to high clay fraction. They are characterized by high compressibility, low shear strength and generally less than 25 kPa (Kishore, 2005). They have following typical characteristics which normally predominantly fined grained if it more than 50% of soil passing through 75μ is sieve.

It has a value of high liquid limit (w_L) and high plastic limit (w_p) together with a high natural water content (NMC). The NMC is even higher than the value of liquid limit (Kishore, 2005). Other than that, soft clay has a low material permeability but the overall permeability can be more.

Parameters	Researchers		
	Chan and Ibrahim (2008)	Robani and Chan (2009)	Ho and Chan (2011)
Bulk Density (Mg/m^3)	1.36	-	-
Specific Gravity	2.66	2.62	2.62
Plastic Limit (%)	31	32	32
Liquid Limit (%)	77	68	68
Plasticity Index (%)	46	36	-

Table 2.1: Physical properties of Batu Pahat soft clay (Chan and Ibrahim, 2008; Robani and Chan, 2009; Ho and Chan, 2011)

The physical properties of Batu Pahat soft clay at RECESS have been experimentally conducted by researchers as shown in Table 2.1. A study carried by Chan and Ibrahim (2008), indicated that clay soil at RECESS, UTHM contained 10.8 % clay, 79.5 % silt and 10.7 % sand. According to Robani and Chan (2009), the clay soil conducted at RECESS, UTHM contained 10.23 % clay, 89.2% silt and 0.57 % sand.

2.1.1 UNDRAINED SHEAR STRENGTH

The term "Undrained Shear strength" describes a type of shear strength in soil mechanics as distinct from drained strength. It depends on a number of factors, the main ones being the orientation of stresses, stress path, rate of shearing and the volume of material such as fissured clays or rock mass.

Undrained strength is typically defined by Tresca theory, based on Mohr's circle and commonly adopted in limit equilibrium analyses where the rate of loading is very much greater than the rate at which pore water pressures that are generated due to the action of shearing the soil may dissipate. An example of this is rapid loading of sands during an earthquake, or the failure of a clay slope during heavy rain, and applies to most failures that occur during construction (Henkel, 1960).

As an implication of undrained condition, no elastic volumetric strains occur, and thus Poisson's ratio is assumed to remain 0.5 throughout shearing. According to Henkel (1960), the Tresca soil model also assumes no plastic volumetric strains occur. This is of significance in more advanced analyses such as in finite element analysis. In these advanced analysis methods, soil models other than Tresca may be used to model the undrained condition including Mohr-Coulomb and critical state soil models such as the modified Cam-clay model, provided Poisson's ratio is maintained at 0.5.

One relationship used extensively by practicing engineers is the empirical observation that the ratio of the undrained shear strength, C_u to the original consolidation stress p' is approximately a constant for a given Over Consolidation Ratio (OCR). This relationship was first formalized by (Henkel, 1960) and (Henkel and Wade 1966) who also extended it to show that stress-strain characteristics of remolded clays could also be normalized with respect to the original consolidation stress. The constant c/p relationship can also be derived from theory for both critical-state and steady-state soil mechanics (Joseph 2012). This fundamental, normalization property of the stress-strain curves is found in many clays, and was refined into the empirical SHANSEP (stress history and normalized soil engineering properties) method (Ladd & Foott 1974).

Based on the values of undrained strength, soft soil are classified into two categories which are undrained strength less than 12 kPa which represents the very soft soil and the undrained strength which less than 25 kPa that represents the soft soil (Kishore, 2005). According to Brand & Brenner (1981), soft clay is defined as clay with shear strength less than 25 kPa.

Undrained strengths determined from undrained triaxial and field vane shear tests are plotted versus elevation and the data combined with piezocone penetration data in Figure 2.1 The data was then analyzed and interpreted to determine a representative average undrained shear strength profile and upper and lower undrained shear strength bounds (Varathungarajan *et al.*, 2008).