UNDRAINED SHEAR STRENGTH OF SOFT CLAY REINFORCED WITH 6MM AND 10MM DIAMETER OF SINGLE BOTTOM ASH COLUMN

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ABSTRACT

In today's construction industry, there are various types of ground improvement techniques are need due to existence of problematic soil like soft soil. Stone column is one of the ground improvement techniques to improve the soft soil strength. Bottom ash, as a residue of coal combustion from coal power plants, has similar properties with sand and potentially 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 column, the disposal problem for bottom ash could extensively be reduced. This research is to show the improvement level in shear strength of soft clay after being reinforced with single bottom ash column. The first study was to determine the physical and mechanical properties of kaolin and bottom ash. The results show that kaolin can be classified as clayey soil and the bottom ash it has relatively similar characteristics to sand. Next, remoulded specimens of 50mm in diameter and 100mm in height of kaolin are tested under Unconfined Compression Test (UCT). A total 35 specimens of kaolin samples were tested using unconfined compression test to determine the shear strength parameter. It can be concluded that the shear strength parameters were affected by the diameter and the height of the column. Diameter for single bottom ash columns are 6 mm, and 10mm. So, the area ratio between the area of the bottom ash column and area of the specimen (A_c/A_s) are 1.44% and 4.0%.The heights of single bottom ash column are 24mm, 36mm, 48mm, 40mm, 60mm and 80mm. So, the height penetration ratios between the heights of column with the height of the specimen (H_c/H_s) are 0.24, 0.36, 0.48, 0.40, 0.60 and 0.8 respectively. Hence, the volume ratio between the volume of the bottom ash column and volume of the specimen (V_c/V_s) are 0.35%, 0.52%, 0.69% 1.60%, 2.40%, 3.20%. The presence of bottom ash column really improved the shear strength. Nonetheless, column longer than 80% of the soil length, did not lead to further increment in shear strength. This is considered as the "critical column length" where used as vertical granular column.

ABSTRAK

Dalam industri pembinaan hari ini, terdapat pelbagai jenis teknik pembaikan tanah diperlukan disebabkan kewujudan tanah bermasalah seperti tanah lembut. Tiang batu ialah satu teknik pembaikan kekuatan tanah lembut. Abu dasar sebagai baki pembakaran batu arang dari kilang tenaga arang mempunyai ciri-ciri serupa dengan pasir dan berpotensi digunakan sebagai tiang batu. Penggunaan produk sampingan perindustrian pada masa kini dikenali disebabkan bahan asli yang tidak boleh diperbaharui semakin berterusan berkurangan Tambahan pula, pengeluaran besar abu dasar daripada hasil pembakaran arang menimbulkan isu pembuangan. Jadi, dengan menggunakan tiang abu dasar, masalah pelupusan yang meluas abu dasar boleh dikurangkan. Penyeldikan ini adalah untuk menunjukkan peningkatan kekuatan ricih tanah liat lembut selepas diperkuatkan dengan tiang abu dasar tunggal. Kajian pertama adalah untuk menentukan sifat mekanik dan fizikal kaolin dan abu dasar. Keputusan menunjukkan kaolin boleh tergolong sebagai tanah bertanah liat dan abu dasar mempunyai persamaan ciri-ciri dengan pasir. Seterusnya, spesimen kaolin terbentuk bergaris pusat 50mm dan 100mm tinggi diuji dengan Ujikaji Mampatan Tak Terkurung (UCT). 35 spesimen kaolin telah diuji menggunakan UCT untuk menentukan parameter kekuatan ricih. Ia dapat disimpulkan bahawa parameter kekuatan ricih terjejas oleh garis pusat dan tusukan ketinggian. Garisan pusat untuk tiang abu dasar tunggal ialah 6mm dan 10mm. Jadi, nisbah penggantian luas kawasan tiang abu dasar (A_c/A_s) ialah 1.44% dan 4.0%. Tusukan ketinggian tiang abu dasar tunggal ialah 24mm, 36mm, 48mm, 40mm, 60mm, dan 80mm. Jadi, nisbah tusukan ketinggian (H_c/H_s) ialah 0.24, 0.36, 0.48, 0.40, 0.60, dan 0.80. Oleh itu, nisbah isipadu tiang abu dasar dengan isipadu spesimen (V_c/V_s) ialah 0.35%, 0.52%, 0.69%, 1.60%, 2.40%, dan 3.20%. Kehadiran tiang abu dasar tunggal terbukti meningkatkan kekuatan ricih tanah liat lembut. Walaubagaimanapun, tiang panjang melebihi 80% daripada panjang tanah tidak menunjukkan kenaikan kekuatan ricih. "Panjang tiang kritikal" dipertimbangkan untuk digunakan sebagai tiang berbutir tegak.

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LIST OF SYMBOLS

A_c	Area of bottom ash column
A_s	Area of specimen
c	Cohesion
D_c	Diameter of bottom ash column
H_c	Height of bottom ash column
G_s	Specific gravity
H_c	Height of column
H_s	Height of specimen
kN	Kilo Newton
kPa	Kilo Pascal
m/s	Metre per second
mm	Milimetre
q	Deviator stress
s	Shear strength
s_u	Undrained Shear strength
V_c	Volume of bottom ash column
V_s	Volume of specimen
w	Moisture content
w_{opt}	Optimum moisture content
ρ_d	Dry density
	Degree

%	Percentage
ϕ	Angle of friction
σ	Effective inter granular normal pressure

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ACAA	American Coal Ash Association
ASTM	American Society for Testing and Materials
BA	Bottom Ash
BS	British Standard
CBR	California Bearing Ratio
LL	Liquid Limit
PI	Plasticity Index
PL	Plastic Limit
UCT	Unconfined Compression Test
US	United States
USCS	United Soil Classification System

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Nowadays, there are extensive growths in development of housing, commercial, industrial, and other infrastructure facilities due to increase of population. The rapid economic development has resulted in an increasing demand for residential housing among urban areas in Malaysia. The government aimed at ensuring that all Malaysians have the chance to obtain an appropriate place to live. Unfortunately, the price of lands keeps on increasing due to the limited availability of the construction site. House and land prices are increasing dramatically and even middle class Malaysian are facing difficulties to own a home. So, the developers take the initiative to do construction on the soft soil area which is not really suitable site for civil construction.

Construction on the poor ground such as soft clay affects the settlement and stability of the structure. According to Jenny (1980), soft clays can be defined as a soft earth, which is plastic, or may be molded with the hands, consisting of hydrous silicate of aluminum. It is the result of the wearing down and decomposition, in part, of rocks containing aluminous minerals as granite. Lime, magnesia, oxide of ferum, and other ingredients, are often present as impurities. The water content in soft clays is higher than its liquid limit; such materials display extremely low yield stresses and represent difficult construction conditions. This is because soft clays are the type of fine-grained soils which change volume when different from elastic deformation, consolidation and secondary compression (Yusof *et al.*, 2006). Soft clays always bring the problems of soil unstable and structure settlement. Therefore, the construction of buildings, roads, bridges canals and railway in soft clay has always been associated with stability problem and settlement (Fakher *et al.,* 1999).

The ground improvement is necessary to modify the soil properties. Utilization of various improvement methods for soft soil particularly soft clay is used in a wide range. This is due to low shear strength quality of soft clay which can lead to excessive settlement (Al janabi and Chik, 2013). It is important to do ground improvement in order to ensure the safety of the constructed building on that area. Without a properly interpreted soil improvement, hazards which lie in the ground beneath the site cannot be known. There are several methods to improve the soft clay properties such as preloading, sand drains, piling, vibrated granular columns, stone column and sand column. Muir Wood *et al.* (2000) and Black *et al.* (2006) have carried out studies to enhance the load bearing capacity of soft soil by installing singular and group of granular columns. The disinterment technique is used by Muir Wood *et al.* (2000) to study the deformed shapes of stone column models and also varied the diameter, length, and spacing of stone column models in order to study the transferred load to the surrounding clay.

Stone columns are found to be a very effective method to improve soft soil properties (Al janabi and Chik, 2013). Ambily and Ghandi (2007) have proven that the vertical granular technique such as stone column has been successfully applied to improve the shear strength of soft soil and also to decrease the settlement for structure foundation. Some of the soil is being replaced with granular material such as sand or crushed rock in stone column method. The depth of the replaced fill depends on the required bearing capacity and the allowable settlement. This techniques lead to great heights of soil replacement and it requires high cost and effort. Fortunately, due to the similarity properties of bottom ash to the sand (Kumar and Stewart, 2003), there is a good chance to use bottom ash as replacement material in stone column.

Bottom ash is the by-product of combustion of pulverized coal (Singh and Siddique, 2013), which is collected from the bottom of furnaces. Bottom ash is a porous, glassy, dark gray material with a grain size similar to the sand (Babcock and Wilcox, 1978). Rogbeck and Knutz (1996) stated that even though bottom ash is similar to natural fine aggregate, bottom ash is lighter and more brittle and has a greater resemblance to cement clinker. Singh and Siddique (2013) also reported that bottom ash sometimes is used as partial substitution of fine aggregate in the production of concrete. There are four coal power plants in Peninsular Malaysia, which are located at Tanjung Bin, Jimah, Kapar, and Manjung. According to Muhardi *et al.* (2010), specifically for Tanjung Bin power plant alone, it has produced 180 ton/day of bottom ash and 1620 ton/day fly ash from 18000 ton/day of coal burning.

Recycle and fully utilization of waste materials have grabbed many attentions in construction field in a way to satisfy the current interest in long term and sustainable development. In addition, the alternate uses of industrial by-product can overcome the shortage supplies of some natural resources that are non-renewable natural material especially in construction field. At the same time, it is to cut the cost of managing the landfill. Hence, the used of bottom ash to substitute the sand in stone column is a good choice it is not only can help to reduce the costs of construction but also reduce the disposal area of bottom ash.

1.2 PROBLEM STATEMENT

The sustainable structure to provide great strength to support loads within the structure is very important. Since we cannot control the process of soil formation, the existing soil on a given site may not be suitable to support the desired facilities such as buildings, bridges and dam because safe bearing capacity of a soil may not be adequate to support the given loads especially construction on soft soil. The major problem related to the soft clay is that it has low shear strength quality which may affect the stability and settlement of the structure. In such cases, the properties of the soil within the zone of influence need to be improved in order to make them suitable to support the subjected loads.

Structure construction is not suitable to construct on the weak soft clay. Many problems rise due to soft clay characteristic. Structures constructed on soft soils may experience problems, such as excessive settlements, large lateral flow sand slope instability (Abdullah and Edil, 2007). For example, during excavation process, many problems mainly associated with the very low soil strength and highly deformable characteristic of soft clay occurred. Due to the bad subsoil condition, the depth of excavation becomes deeper and deeper. So, the structure design must be plan properly. From here, we know the understanding and analyzing the engineering characteristic should be enough in order to make people in this field realize how important the soil characteristic to the structure. It is important to choose the most appropriate material and load resisting system, including considering the possibility of reuse or recycling of materials throughout the design and planning phase.

Hence, ground improvement is needed to modify soil properties and increase shear strength of soft soil. The selection of ground improvement techniques for soft clays depends on the design criteria of infrastructure as well as on the thickness of the soft layer. Vertical granular column is one of the economic ground improvement techniques to strengthen soil. According to Murugesan and Rajagopal (2006), the major advantage with this technique is the simplicity of its construction method. The stone column technique is preferred because it reduced settlements and accelerated consolidation settlements due to reduction in flow path lengths. When the stone columns are installed in very soft soils, they may not obtain significant load capacity due to low lateral confinement. McKenna *et al.* (1975) reported cases where the stone column was not restrained by the surrounding soft clay, which led to excessive bulging, and also the soft clay squeezed into the voids of the aggregate. The squeezing of clay into the stone aggregate eventually reduces the bearing capacity of stone column. Also the lower undrained cohesion value demand more stone column material.

Bottom ash is used as substitute material to sand in the stone column method. This is because in previous studies have stated 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 the construction can be reduced. Nowadays, construction industry chooses to do the utilization of the industrial by-products as additional materials due to the continuous reduction of non-renewable natural material which are natural aggregates in construction. By recycling the bottom ash, it produces usable materials at much less environmental cost than materials from primary sources. So, the cost regarding the natural aggregates use, energy and water consumption can be reduced.

By utilizing the bottom ash, the disposal area of bottom ash also can be reduced. The disposal area should be reduced because the substantial amount that disposed in the landfills can really harm the human life and environment. It has been confirmed US EPA (2010) that coal ash commonly contains some of the world's deadliest toxic metals such as arsenic, lead, mercury, cadmium, chromium and selenium. These and other toxicants in coal ash can cause cancer and neurological damage in humans. They can also harm and kill wildlife, especially fish and other water-dwelling species. In short, coal ash toxics have the potential to injure all of the major organ systems, damage physical health and development, and even cause a death.

1.3 OBJECTIVES

The main focus of this study is to show the improvement level in shear strength of soft clay after being reinforced with single bottom ash column. Soft clay has been represented by compacting kaolin. This study is carried out to achieve objectives as follow:

i. To determine physical and mechanical properties of bottom ash and kaolin clay samples;
ii. To determine undrained shear strength of soft clay reinforced with single bottom ash column;
iii. To establish correlation chart relating to undrained shear strength with various dimensions.

1.4 SCOPE OF STUDY

The scope of this study is simplify process for gather the information and data collection about the test conducted to determine the physical and mechanical properties of bottom ash and kaolin. In this study, several laboratory tests are conducted by using sample provided within given time limit. Some laboratory works are done to determine the physical and mechanical properties of bottom ash such as specific gravity test, sieve test, direct shear test, constant head permeability test, and standard compaction test. Laboratory test in determining the physical and mechanical properties of kaolin are liquid limit and plastic limit test, specific gravity test, standard compaction test, constant head permeability test and hydrometer test.

The undrained shear strength of soft clay reinforced with single bottom ash column is determined form unconfined Compression Test based on (BS 1377, 1990). Every batch of kaolin sample is produced by using compaction method. The specimens are 50mm in diameter and 100mm in height. Diameter for single bottom ash columns are 6mm, and 10mm. So, the area ratio between the area of the bottom ash column and area of the specimen (A_c/A_s) are 1.44%, and 4.00%. The heights of single bottom ash column are 24mm, 36mm, 48mm, 40mm, 60mm and 80mm.By this, the height penetration ratios between the heights of column with the height of the specimen (H_c/H_s) are 0.24, 0.36 and 0.48, 0.40, 0.60, and 0.80 respectively. Hence, the volume ratio between the volume of the bottom ash column and volume of the specimen (V_c/V_s) are 0.35%, 0.52%, 0.69% 1.60%, 2.40%, 3.20%.

1.5 SIGNIFICANT OF STUDY

The main purpose of this study is to determine the undrained shear strength of soft clay after reinforced with single bottom ash column. Therefore, several experimental procedures are carried out to know the physical and mechanical properties of bottom ash and kaolin clay sample. By knowing the properties of bottom ash and kaolin, we can evaluate the suitability of bottom ash in replacing sand in sand column.

In Malaysia the used of bottom ash from coal fire boiler power plant become one of the serious environmental problems. Therefore, new alternative needed to recycle and reuse them to avoid those problem from become more serious environmental problem. 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 this study, bottom ash represented the recycled aggregate that can be used as replacement materials. When the sand is replaced with bottom ash, we can reduce the usage of natural aggregate which is non- renewable natural material.

The used of bottom ash column increased the bearing capacity of soft soil and settlement of structure foundation is reduced. Hence, this would increase significantly the availability of marginal sites for more long-term construction.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Literature review is a thesis, journal or book that has been published on a topic by accredited scholars and researchers. The purpose of literature review is to explain the background of the study that combine with ideas and knowledge and also the strength and weakness of the topic.

For this thesis, the topics covered are sustainable construction, small scale modeling, soft clay, bottom ash and ground improvement of granular column.

2.2 SUSTAINABLE CONSTRUCTION

Sustainable construction is generally described as the application of sustainable practices to the activities of the construction sector. Parkin (2000) defined sustainable construction as a construction process which incorporates the basic themes of sustainable development. According to Protrend Arrow Construction, PAC (2009), sustainable construction is the creation and responsible management of a healthy built environment based on the resource efficient and ecological principles. The construction processes would thus bring social awareness, environment responsibility, and economic profitability objectives to the fore in the built environment and facilities for the wider community (Langston and Ding, 2001).

Khalfan *et al.* (2011) stated that construction industry involves a huge amount of stakeholders. The stakeholders are usually reffered to those who produce, develop, plan, design, build, alter and maintain the built environment. Building material suppliers, manufacturers, clients, end users and occupiers are some of the skateholder that are involved in the construction industry. This statement is supported by the previous researcher. Langston and Ding (2001) that sustainable construction can be best described as a subset of sustainable development, which encloses matters such as tendering, site planning and organisation, material selection, recycling, and waste minimization.

Construction has a significant effect on quality of life. Its outputs vary the nature, function and appearance of the town and countryside in which people live and work. The construction industry makes many positive contributions to society, but it also has negative impacts on the environment (Khalfan *et al.*, 2011). These include soil erosion, sendimentation, flash floods, destruction of vegetative, dust pollution, depletion of natural resources and the use of building materials that can be harmful to human health (CIDB, 2007).

The awareness of the negative impacts has led to the growth of studies on solutions for practicing sustainable construction across a project life cycle (Tam and Le, 2006). However, according to Khalfan *et al.* (2011), the effectiveness of sustainable constructions has been limited in practice due to the profit driven culture in the industry. The cost, quality, and scheduling have been the determinants to ensure maximum benefits to the construction firms. Zainul Abidin and Pasquire (2005) have interpreted the sustainable principals concerning the construction industry.

Table 2.1: The interpretation of the principles of sustainability within the construction industry

The interpretation of the principles of sustainability within the construction industry
Show concern for people by ensuring they live in a healthy, safe and productive built environment and in harmony with nature.
Safeguarding the interests of future generations while at the same time, meeting today's needs.
Minimizing damage to the environment and its resources. Improving the quality of buildings and services, create jobs opportunities and promote social cohesiveness.
Using technology and expert knowledge to seek information and in improving project efficiency and effectiveness.

Source: Khalfan *et al.* (2011)

2.3 GROUND IMPROVEMENT OF GRANULAR COLUMN

To economically develop marginal sites, a number of ground improvement techniques have been widening. Stone columns are one method of ground improvement having a proven record of experience as the concept was first applied in France in 1830 to improve an inhabitant soil. Stone columns have been used in many difficult foundation sites throughout the world to increase the bearing capacity, to reduce the total and differential settlement, to increase the rate of consolidation, to improve slope stability of enbarkments and also to improve the resistance to liquefaction (Alamgir *et al.*, 1996). During the past decades, many research works have been reported in literature based on laboratory model tests and large scale field load tests, to investigate the behavior of stone column treated grounds.

Bergado *et al.* (1984) conducted full scale load tests and indicated that the granular piles increased the bearing capacity more than 3–4 times that of untreated ground. In addition, the adjacent piles acted independently when the pile spacing is 3 times the pile diameter or greater. Besides, Bergado and Lam (1987) studied the behavior of granular piles with different densities and different proportions of gravel and sand on soft Bangkok They reported that higher ultimate pile capacity for pure gravel increases with the density and friction angle of the granular materials. Greenwood (1970) also reported that the degree of improvement in the bearing capacity of clays with granular insertions depends on the lateral support provided by the clay to the column, the diameter of the column, and the degree of compaction of the column.

Li *et al.* (2000) investigated the interactions between gravel column inclusions and surrounding soil in composite ground through triaxial model tests. The result showed that the modules and strength of gravel strongly depend on the confining pressure and dilatency of gravel brings lateral interaction between column and surrounding soil. In investigation done by McKelvey *et al.* (2004), a transparent medium with 'clay-like' properties is used to allow visual monitoring of the columns throughout foundation loading. They found that in the case of 'short' columns, length per diameter (i.e. L/D = 6), bulging took place over the entire length of the columns and they punched into the clay beneath their bases. The 'long' column (L/D = 10) deformed significantly in the upper region whereas the bottom portion remained undeformed. This suggests that there was little or no load transfer to the base in longer columns, with failure arising from bulging or shear. Then, Black *et al.* (2006) developed a more sophisticated triaxial apparatus in which the boundary conditions imposed on a clay bed (reinforced with stone columns) can be regulated.

Black *et al.* (2007) conducted tests on isolated stone column and on a group of three columns with same area replacement ratio with different lengths under drained triaxial conditions. They concluded that grouping of columns can lead to a possible reduction in the stiffness when compared with a single column at similar area replacement ratio. Moreover, Najjar *et al.* (2010) investigated the improvement in the mechanical properties of soft clays reinforced with sand columns. They found that sand columns improved the undrained strength significantly even for low area replacement ratios accompanied by a decrease in pore pressure generation during shear and an increase in Young's modulus. The drained shear strength parameters were found to be relatively unaffected by the sand column reinforcement, except for fully penetrating columns with high area replacement ratios.

From the experimental investigation of stone columns in layered soils, Shivashankar *et al.* (2011) found that the presence top soft layer has a significant influence on the stiffness, load bearing capacity and bulging behavior of stone columns. Stiffness and load carrying capacity of stone column treated layered ground decreases with the increase in the top weak layer thickness. Entire bulging was noticed mostly in the top weak layer zone. Based on Bae *et al.* (2002), the bearing capacity of stone column is affected by undrained strength of surrounding ground and area replacement ratio (or pile spacing) of composite ground, installation of mat and diameter of column. They found that the failure mechanism and various parameters influencing the behavior of end bearing stone column groups after conducting loading tests and unit cell consolidation tests.

2.4 BOTTOM ASH

Bottom ash and fly ash are the two types of ashes produced by thermal power plants in the process of the generation of electricity. Bottom ash, being heavier, and falls through the bottom of the furnace where it is collected in a hopper, whereas fly ash, being very fine, is carried through the furnace with the exhaust gases and is collected by ash precipitators (Huang, 1990). In dry pulverized bottom furnaces, ashes are collected as dry solids before complete melting occurs. These solid particles are collected in a collection hopper and removed by high- pressure water jets and conveyed to a disposal pond or a decant basin for dewatering, crushing, and stockpiling for disposal or use (Hecht and Duvall, 1975).

Ksaibati and Sayiri (2006) showed that the ingredients in bottom ash are the same as those in mud and silt that, when combined with organic matter, eventually become coal. They also stated that bottom ash is granular and have the same upper and lower particle size limits as concrete sand. Besides, they discovered that bottom ash is angular in shape and may range in color from medium brown, to gray, to almost black and consists of melted sand and lime, with smaller amounts of oxides containing aluminum, iron, magnesium, sulfur and trace materials.