UNDRAINED SHEAR STRENGTH OF SOFT CLAY REINFORCED WITH 6MM AND 8MM DIAMETER GROUP OF BOTTOM ASH COLUMN

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ABSTRACT

This study is to determine the undrained shear strength of the soft clay reinforced with the bottom ash column. The coal combustion products are generated from the coal combustion process in order to produce electricity. The coal combustion product consists of fly ash, bottom ash, boiler slag and flue gas desulfurization (FGD) material. This coal combustion product is disposed in the landfill, if this situation continued it will utilize lots of space. By reusing the waste or by product bottom ash as a raw material in the construction, the usage of the non-renewable natural material such as aggregate can be reduced.The angular shape of the bottom ash particle is similar to the aggregate shape, the angular shape is important in order to obtain a strong bond between the materials in the construction. Soft clay is known as the problematic soil because of the weakness in strength characteristic and high compressibility. Due to the soft clay characteristic the ground improvement needs to be conducted in order to increase and improve the soft clay strength. Stone columns are one of the ground improvement methods that usually been conducted toward the soft clay.There are several advantages that can be obtain by using the stone column as the ground improvement method such as the soil bearing capacity can be increased, the total and differential settlements can be minimize and accelerates the consolidation settlement. Sustainable construction also known as the green construction, it is an action which aims to reduce the environmental impact of the construction over its entire lifetime, at the same time it has to be safe and comforts toward its occupants. The sustainable constructions are the development that meets the need of the present without compromising the environmental aspects for the future generation. By reuse, reduce and recycle the sustainability in construction can be achieve. The aim of this study is to investigate the improvement of undrained shear strength of soft clay reinforced with the group bottom ash column in which the physical characteristic and mechanical characteristic of kaolin clay and bottom ash are determined. The undrained shear strength parameter of soft clay and soft clay reinforced with various dimensions of the group bottom ash column are compare to determine whether there is any increment after the insertion of the bottom ash column. Correlations relating the undrained shear strength parameter with various dimensions of the group bottom ash column installed in soft clay are established. Based on the results that been obtained from this study indicate that the shear strength of the soft clay reinforced with bottom ash column are improved.

ABSTRAK

Kajian ini adalah untuk menentukan kekuatan ricih tanah liat lembut yang diperkuatkan dengan tiang abu bawah. Produk-produk pembakaran arang batu terhasil daripada proses pembakaran arang batu untuk menghasilkan tenaga elektrik. Produk pembakaran arang batu terdiri daripada abu terbang, abu bawah, dandang sanga dan gas serombong desulfurisasi (FGD). Produk pembakaran arang batu ditempatkan di tapak pelupusan, jika keadaan ini berterusan ia akan menggunakan ruang yang banyak. Dengan menggunakan semula sisa atau produk-produk pembakaran arang batu sebagai bahan mentah dalam sektor pembinaan dapat mengurangkan penggunaan bahan semula jadi. Bahan semula jadi ialah bahan yang digunakan dalam masa yang lebih singkat daripada tempoh yang diambil untuk terhasil, contoh dalam kes ini agregat. Bentuk sudut zarah abu bahagian bawah adalah sama dengan bentuk agregat, bentuk sudut adalah penting untuk mendapatkan satu ikatan yang kuat antara bahan-bahan dalam pembinaan. Tanah liat lembut yang dikenali sebagai tanah bermasalah kerana kelemahan dalam ciri kekuatan dan kebolehmampatan yang tinggi. Disebabkan ciri-ciri tanah liat lembut proses pembaikan tanah perlu dijalankan untuk meningkatkan dan membaikpulih kekuatan tanah liat lembut. Tiang batu adalah salah satu kaedah pembaikan tanah yang biasanya dijalankan ke arah tanah liat lembut. Terdapat beberapa kelebihan yang boleh diperolehi dengan menggunakan tiang batu sebagai kaedah pembaikan tanah seperti meningkatkan keupayaan galas tanah, mengurangkan jumlah dan perbezaan penempatan dan mempercepatkan penyelesaian penggabungan tersebut. Pembinaan mampan juga dikenali sebagai pembinaan hijau, ia adalah suatu tindakan yang bertujuan untuk mengurangkan kesan alam sekitar daripada pembinaan atas seluruh hayatnya, pada masa yang sama ia perlu selamat dan keselesaan ke arah penghuninya. Pembinaan mampan adalah pembangunan yang memenuhi keperluan masa kini tanpa menjejaskan aspek-aspek alam sekitar untuk generasi akan datang. Dengan penggunaan semula, mengurangkan dan mengitar semula kemampanan dalam pembinaan boleh dicapai. Tujuan kajian ini adalah untuk menyiasat peningkatan kekuatan ricih tanah liat lembut diperkukuhkan dengankumpulan tiang abu bawah di mana ciri ciri mekanikal dan fizikal tanah liat kaolin dan abu bawah ditentukan. Kekuatan ricih taktersalir parameter tanah liat lembut dan tanah liat lembut diperkukuhkan dengan pelbagai dimensi kumpulan tiang abu bawah yang dibandingkan untuk menentukan sama ada terdapat apa-apa kenaikan selepas kemasukan tiang abu bawah. Korelasi berkaitan parameter kekuatan ricih dengan pelbagai dimensi kumpulan tiangabu bawah dipasang di tanah liat lembut dihasilkan. Berdasarkan keputusan yang diperolehi daripada kajian ini menunjukkan bahawa kekuatan ricih tanah liat lembut diperkukuhkan dengan tiang abu bawah dipertingkatkan.

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LIST OF SYMBOLS

A_c	-	Area of bottom ash column
A_s	-	Area of kaolin clay sample
c	-	Cohesion
C_r	-	Relative consistency
D_c	-	Diameter of bottom ash column
G_s	-	Specific gravity
H_c	-	Height of bottom ash column
H_s	-	Height of kaolin clay sample
I_L	-	Liquidity index
m/s	-	Meter per second
mm	-	Milimeter
μm	-	Micrometer
γ_d	-	Dry unit weight
P	-	Load
q_u	-	Unconfined compression stress
s_u	-	Undrained shear strength
Δs_u	-	Improvement shear strength
w	-	Moisture content
w_{opt}	-	Optimum moisture content
w_P	-	Plastic limit
w_L	-	Liquid limit
w_S	-	Shrinkage limit
ε	-	Strain
^{o}	-	Degree

LIST OF ABBREVIATIONS

AASHTO	-	American Association of State Highway and Transportation Officials
ACAA	-	American Coal Ash Association
BS	-	British Standard
EPRI	-	Electric Power Research Institute
FKASA	-	Faculty of Civil Engineering and Earth Resource
IEA	-	International Energy Agency
LL	-	Liquid Limit
PI	-	Plastic Index
PL	-	Plastic Limit
RMRC	-	Recycled Materials Resources Centre
SL	-	Shrinkage Limit
UCT	-	Unconfined Compression Test
UMP	-	University Malaysia Pahang
USCS	-	Unified Soil Classification System
kN	-	Kilo Newton
kPa	-	Kilo Pascal

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

In this day and age, the government have tried their best to change our nation perspective toward the protection of the environment which the greener environment can lead us to a better tomorrow. As a developing country, the demands for the electricity are increasing. There are several resource that been used in the electricity generation. Based from the Figure 1.1, the highest material that been used in the world electricity generation by fuel is coal (42%) followed by gas (21%) and the least material that been used in the world electricity generation by fuel is other renewables (3%). The coal combustion processes are conducted in order to produce the electricity, the coal combustion processes are depending on the demands on the electricity. According to Abubakar and Baharudin (2012), installed capacity of the coal power plants in the year 2010 will be 7,200 megawatts (about 40% of the total) requiring about 22.5 million tonnes of coal that is for 8,200 megawatt capacity.

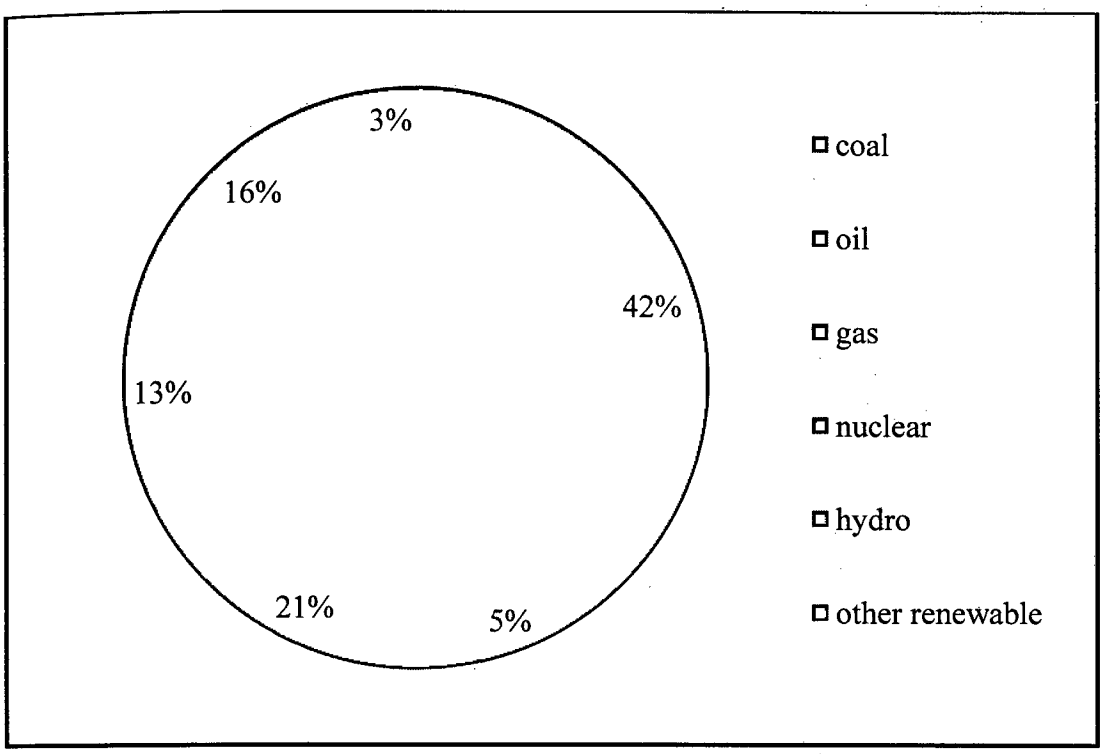

Figure 1.1: Total World Electricity Generation by Fuel

Source: International Energy Agency, IEA (2011)

The coal combustion products are produced from the coal combustion activity. The main coal combustion products are the fly ash and the bottom ash. The amounts of the coal combustion products that produced from the coal combustion activity are high since the amount of the fly ash and the bottom ash that been produced from each activity are about 10% of the total amount of the coal. The coal combustion products are classified as waste and it is disposed in large quantities in the landfill since the amount of the coal that been used are high. In order to reduce the amount of the coal combustion product that been disposed in the landfill the fly ash and the bottom ash are used in the construction.

According to American Coal Ash Association (ACAA, 2002), the bottom ash characteristic is a dark grey, granular, porous, predominantly sand size material which is suitable to be used in the constructions. Bottom ash has been used as an alternative raw material in the construction to replace sand and aggregate. Since the aggregate is a non-

renewable material it is a good option to reduce the aggregate usage by using an alternative material. Non-renewable material is a natural resource which consumed a lot faster than the time that the materials need to be produced by the nature. The non-renewable material cannot be produced, grown or generated. Once it is finished, there is no more available for the future needs. The bottom ash application in the construction industry should be broader in order to reduce the usage of the non-renewable material.

Soft clay is known as the problematic soil because of the soft clay weakness in strength characteristic and high compressibility. Due to the soft clay characteristic the ground improvement needs to be conducted in order to increase and improve the soft clay strength. Before the project can be proceed with the construction the soil has to meet the project requirements, the soil improvement should be done first toward the soil. There are several soil improvement methods that can be used to improve the soil strength such as stone columns, grouting, prefabricated vertical drain and much more. From this soil improvement phase the soil is stabilized, hence the soil performance will be improved. Based on this study we can determine whether the soft clay reinforced with the bottom ash column is suitable or not as the soil improvement method toward the soft clay.

As a nation we can play our part to practice the green environment concept in our daily life, which is to reduce, reuse and recycle. The engineer also tried to practice the green environment concept which they are reusing the wastes that are suitable for the construction in order to reduce the space that are occupied by the waste in the landfills. Lots of space, money and time are used to manage the coal combustion products in the landfill. The best solution that can be used is to reuse the coal combustion products in the construction field. Before the waste can be used in the construction, the waste needs to be examined to determine whether it is suitable to be included in the construction. There are several aspects that need to be determined such as the physical characteristic of the waste, the chemical content of the waste, the decay factor of the waste and much more.

1.2 PROBLEM OF STATEMENT

The bottom ash is the residue from the coal combustion process in which the coal being used to produce energy or heat. In another word the energy that been produced by the coal is electricity. According to Abubakar and Baharudin (2012), Tanjung Bin power station produces 180 tonnes per day of bottom ash and 1,620 tonnes per day of fly ash from 18,000 tonnes per day. From here we can see that the bottom ash and the fly ash that been produced in a coal combustion process of 18,000 tonnes of coal are very high at Tanjung Bin power station. Due to the coal combustion products amount that been produce is high, the disposal of coal ash has reached an alarming proportion. The fly ash and the bottom ash are classified as the waste and it is disposed in the landfill, this situation can lead toward the maximum space usage and also are costly

The amount of the fly ash and bottom ash produced are higher according to the electricity power demands. According to the American Coal Ash Association (ACAA, 2004), in 2003 over 121 million tons of coal combustion products were generated which is fly ash (70 million tons), bottom ash (18.1 million tons), boiler slag (1.8 million tons) and flue gas desulfurization (FGD) material (31.6 million tons). From here we can see that the coal combustion products that's been produced in a coal combustion activity are high especially for the fly ash and bottom ash, which about 10% to 20% from the total of the amount of coal that been processed.

The soft clay is known as the problematic type of soil because it is high in compressibility and weak in the strength characterisation. Due to the factor that the soft clay is high in the compressibility, the settlement can occur to the structure of the soft clay. Settlement normally occurs when the soil cannot resist the force that been submitted to it. The settlement can easily happen toward the soft clay due to its finer particle, settlement is dangerous because it can lead to the structural failure. The soft clay is high in moisture content because of the particle size of the soil are small so it is difficult for the water to go through. If untreated, the soft clay abilities are limited and it is also not safe to the user. The soft clay can only support about 3m instant filling and about 1m of final settlement without treatment.

1.3 OBJECTIVE OF STUDY

This study is aimed to investigate the improvement of undrained shear strength of soft clay reinforced with the bottom ash column. Thus the objectives of this study are;

1. To determine the physical characteristics of kaolin clay and bottom ash, and morphological characteristic of bottom ash.
2. To determine the undrained shear strength parameter of soft clay and soft clay reinforced with various dimensions of the group bottom ash column.
3. To establish correlations relating the undrained shear strength parameter with various dimensions of the group bottom ash column installed in soft clay.

1.4 SCOPE OF STUDY

In this study the clay samples are formed in the 50mm diameter and 100mm height cylinder by using the customize mould. There are 3 specimens that been tested in every sample of the clay model sample. The element that differentiated the 3 specimen with one and another is the diameter and the height of the bottom ash column. The bottom ash columns are inserted into the soft clay to reinforce the soft clay model sample. The diameters of the bottom ash column are 6mm and 8mm, this column diameters are obtained based on the area of the column over area of soil $\left(\frac{A_c}{A_s}\right)$ calculation. The height of the bottom ash column for 6mm are 24mm, 36mm and 48mm, while for the 8mm diameter the height of the column are 32mm, 48mm and 64mm which obtains from the height of the column over the height of soil$\left(\frac{H_c}{H_s}\right)$. The group bottom ash columns are installed toward the clay model sample based on the certain measurement. The volume of the bottom ash columns is obtained from the ratio of the volume of the column over the volume of the soil$\left(\frac{V_c}{V_s}\right)$. The moisture content of the clay model samples are 16% of the total clay sample weight.

All of the experiments and testing were conducted and analysed in the University Malaysia Pahang (UMP), Faculty of Civil Engineering and Earth Resource (FKASA) Geotechnical laboratory. In this study the major prioritized test is the

unconfined consolidated test. There are two groups of test that been conducted toward the material, which is the test that been conducted toward kaolin and bottom ash. The test that been conducted toward kaolin in order to determine the kaolin physical characters are atterberg limit test, specific gravity test, standard compaction test, falling head permeability test ,hydrometer test and unconfined compression test.

To determine the physical characteristic of the bottom ash there are several tests that need to be conducted toward the bottom ash sample. The test that been conducted toward the bottom ash sample are specific gravity test, dry sieve test, direct shear test, constant head permeability test and standard compaction test. The controlled specimen will be taken from the sample without inserting the bottom ash column toward the soft clay model sample. The purpose of the controlled specimen is to determine whether the bottom ash column that been inserted toward the soft clay model sample did contribute to increase the soft clay strength.

1.5 SIGNIFICANCE OF STUDY

This study is aimed to determine the improvement of undrained shear strength of the soft clay reinforced with the bottom ash column in the laboratory scale modelling. The laboratory test that was conducted are to determine the physical characteristic and the mechanical characteristic of the bottom ash, from all the tests that been conducted in this study we can determine whether the bottom ash characterisations are suitable to be used as the granular material in the stone column.

This study is conducted as another method of construction which the coal combustion product can be used and we can enhance the field of the construction that the coal combustion products are included. Considering the amount of the coal combustion product that been used in the soil improvement method are only 140,092 tons of the total coal combustion product utilization in 2012, based on the coal combustion product production and usage survey report that been conducted by the ACAA (2013).

This study is verified whether the bottom ash column can increase and improve the strength characteristic of the soft clay similar to the stone column or not. By the accomplishment of this study we can get to the bottom of the soft clay as the problematic clay issue and also can reduce the amount of bottom ash that being disposed in the landfill. By recycling the bottom ash we can save money, nature resource and also the energy consumption.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Coal combustion products are residue from the coal combustion activity. The coal combustion activities are conducted in order to produce electricity. Coal combustion products contain of fly ash, bottom ash, boiler slag and flue gas desulfurization (FGD) material. According to ACAA (2004), in 2003 over 121 million tons of coal combustion products were generated. From here we can see that the coal combustion product that been produced from coal combustion activity are high. All of the coal combustion products are consider as waste and disposed in landfill. All of this waste will required a lot of space, time and money. To reduce the amount of coal combustion product that been landfilled, it has been used in the construction industry as the replacement material for aggregate and sand. Soft clay known as the problematic clay, due to the lack of strength characterization and high in compressibility, because of its weakness the ground improvement needs to be conducted toward the soft clay before construction can be proceeds with.

2.2 SUSTAINABLE CONSTRUCTION

Sustainable construction could be defined as the creation and responsible management of healthy built environment based on resource efficiency and ecological principles (Marhani *et al.*, 2013). The resources efficiency can be classify as the method of maximizing the source of material, income, benefits and other related things that can be produced in order to function effectively. Ecological principles are consists of 5 element, such as sustainable use, integration, precautionary, inter-generational and intra-generational equity and internalisation of external environmental costs.

In ecological principles the sustainable use are described as the natural resource that should be used in appropriate manner since the natural resources are non-renewable material so the alternative raw material should be consider. Integration is defined as an action that the economic and environmental aspects need to be combined in order to achieve the sustainable concept. Precautionary is the particular option and action that been taken in order to avoid any risk and harm toward the environment. Inter-generational and intra-generational equity mean the present generation to ensure the health, diversity and productivity of the environment are preserved for the future generation while accomplishing the development. Internalisation of external environmental costs are the principle that require the environment aspects to be taken for both long term and short term through the assets and services that been accommodate.

Sustainable construction also known as the green construction, it is an action which aims to reduce the environmental impact of the construction over its entire lifetime, at the same time it has to be safe and comforts toward its occupants. The sustainable constructions are the development that meets the need of the present without compromising the environmental aspects for the future generation. From the sustainable construction we can reduce the construction, demolition and excavation waste to the landfill.

The sustainable construction can be divided into three groups, which the sustainable architecture, sustainable material and sustainable building. The sustainable architecture is the first phase where the sustainable concepts are implemented. In order to achieve the sustainable architecture the building that been design must fulfil the economic principles, social and ecological sustainability. The sustainable architecture also have to pay attention toward the waste management, energy efficiency and using the low impact material in the construction.

The sustainable material is the materials that are given a low impact toward the environment and also can reducing the building expenditure. The recycled material and the rapidly renewable material can be used in order to reduce the building. The non-toxic material can be used in order to avoid the high impact toward the environment. The sustainable building are consist of efficient usage of resources, increased the productivity, protecting the occupier health and also minimizing the waste and the material impact toward the environment.

In order to achieve the sustainable construction concept the designers and the contractors need to use the building practices that will prevent any long term damage from the construction toward the environment. The building that was designed and build based on the sustainable concept are energy efficient, save towards the user and reduced the amount of waste and pollution that generated during the building entire lifetime. The coal combustion products have been used in the construction for the past decade. By using the coal combustion product in the construction the sustainable construction concept are implemented.

2.3 SOFT CLAY

Clay is formed by the weathering of rocks for a long period of time. The most common types of clay are kaolinite, illite and montmorillonite. Soft clay is known as the weak type of soil. This is because it has a lot of deficiency compared to the other type of soil. The soft clay are usually presence in the low land areas that located near to the sea coast, in the rivers area and in the area where the runoff is restricted and the organic matter in the soil is in the considerable amount. The soft clay need to be classified physical and also the type of the clay minerals if possible. According to Head (2006), classification is usually accomplished by means of the plasticity chart (also referred to as the A-line chart). This is a graphical plot of the plasticity index (I_P) as ordinate against liquid limit (w_L) as abscissa. Based on this statement the value of the liquid limit (w_L) and plastic index (I_P) can be obtained by perform the Atterberg limit test. The plasticity chart is shown in the Figure 2.1.

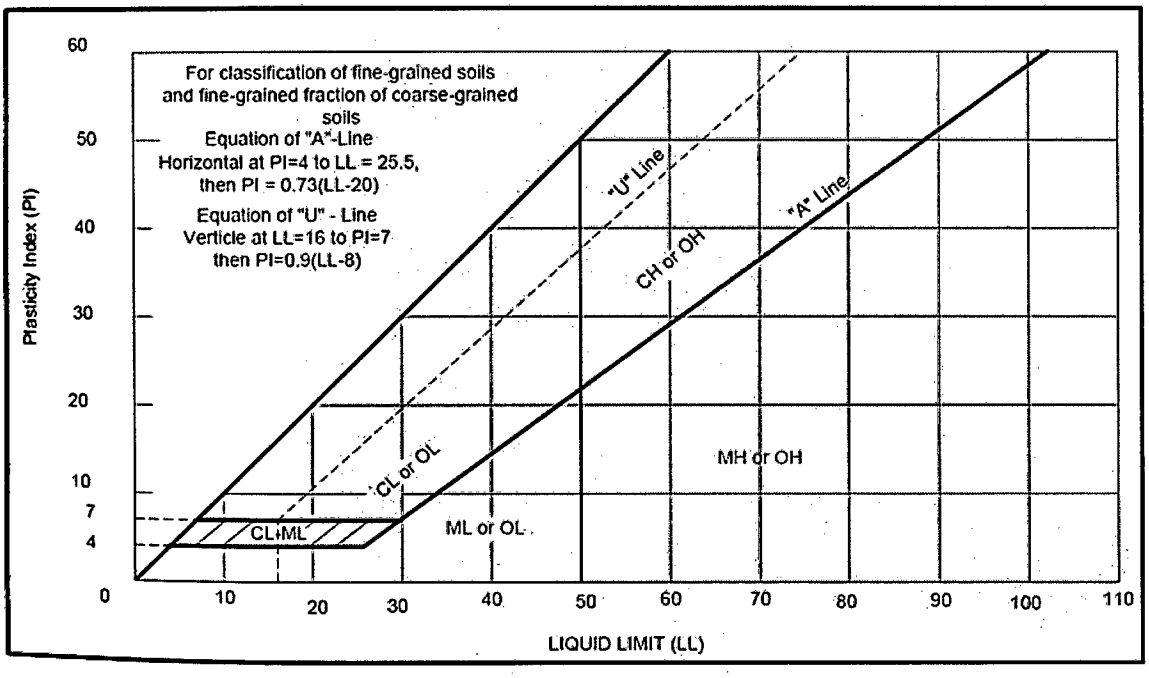

Figure 2.1: Plasticity chart

Source: Das (2008)

According to (Brand and Brenner, 1981), soft clay is defined as clay with shear strength less than 25kPa, based on this statement the soft clay can be proven as the low strength soil. Besides the weakness in strength, the soft clay also is significantly affected by water. Because the soft clay is significantly affected by water, the moisture content of soft clay is high. Moisture content is the mass of water that can be eliminated from the soil by heating. Soft clay is high in plasticity. Plasticity is the medium that allow the soil to be deformed without the soil crack or crumble. According to Wesley (2010), clay consists of very small particles and possesses the properties of cohesion and plasticity, which are not found in sands and gravels.

Soft clay consists of a very fine particle of soil according to McCarthy (2007), clay soil has particle sizes less than about 0.005mm. Unified Soil Classification System (USCS) have stated that the fine-grained soils are not classified by grain size but according to plasticity and compressibility. From this statement we can classify that soft clay as a fine grained soil not only because of the grain size but also because of the soft clay are high in compressibility. Based on the Table 2.1 the clay size limit is less than 0.002mm which categorised the soft clay as the fine-grained soils or the cohesive soils.

Table 2.1: Principle soil group and their particle size limits

COARSE-GRAINED SOILS Or granular materials or non-cohesive soils				**FINE-GRAINED SOILS** Or cohesive soils	
Gravel	Sand			Silt	Clay
	Coarse	Medium	Fine		
60	2	0.6	0.2	0.06	0.002
Size limits (mm)					

Source: Wesley (2010)

The soft clay is high in the compressibility properties, it actually exposing high risk toward the structure on top of the soil because the major factor that can lead toward the settlement is high compressibility. As we know the settlement are dangerous toward the structure because it can lead to the cracking and also structure failure. The reason of soft clay weakness in strength characteristic is because of the soft clay stiffness can be

simply affected. The soft clay is high in the friction factor. Friction factor of the stone column is an important factor for the soft clay ground improvement method because friction is the major concept of the stone column.

Due to the factor that the soft clay are significantly affected by water and the moisture content of the soft clay are high, the dissipation through soil pore is slow and this situation indirectly shown that soft clay is low in permeability. Soil permeability is the soil pore system that permits fluid to flow. The permeability is important toward the contaminant and heat transport through the porous media.

This is stated by Barends (2011), for clays the permeability is related to the free water space (non-hydrated) and it is usually small. According to the Table 2.2 clay is poor in drainage, which means the clay is low in permeability and high in moisture content. The high moisture content level of the soil is dangerous because with the presence of the water the soil condition could be unstable.

Table 2.2: Permeability values and classification

k [m/s]	1	10^{-2}	10^{-4}	10^{-6}	10^{-8}	10^{-10}
Drainage	Good		Moderate		Poor	
Class	Large	moderate	small	Very small	Relatively impervious	
Soil type	Boulders	Gravel	Clean sand	Silty sand	Clay	
Correlation	Grain size distribution			Density	Clay index	

Source: Barends (2011)