STRENGTH OF SOFT CLAY REINFORCED WITH 10 MM SINGLE CRUSHED COCONUT SHELL (CCS) COLUMN

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ABSTRACT: Stone column can be used as a ground improvement technique where a portion of soft soil is replaced with granular material such as stone or sand. The benefit of using stone columns in low strength soil has been proven as an efficient method to improve the bearing capacity and reduce settlement of soft soils. This study aims to investigate the improvement in shear strength of soft clay by embedded with a single crushed coconut shell (CCS) column. The cost of soil improvement can be reduced because of CCS is a waste material. This paper was done by determining the physical and mechanical properties of kaolin and CCS as well as the effect of height penetration ratio of a single CCS column on shear strength characteristics. Unconfined Compression Test (UCT) was conducted for 4 batch kaolin samples including a control sample in order to determine the shear strength. Each batch involved four samples to find the accurate value. The research variables are the height of crushed coconut shell column which is 60 mm, 80 mm and 100 mm where the column penetration ratio is 0.60, 0.80 and 1.00 respectively. A total of 16 unconfined compression tests had been conducted on kaolin sample with dimensions of 50mm in diameter and 100 mm in height. The increment of shear strength by embedded with crushed coconut shell columns is 19.02 %, 34.76 % and 24.34 % for with 4 % area displacement ratio at column penetration ratio of 0.60, 0.80 and 1.00 respectively. From the results obtained, the relationship between shear strength increases is influenced by the height of the column. The maximum column height (full penetration) does not generate the highest strength and it proves that "critical column length" theory is true in this study.

Keywords: Ground Improvement Technique, Stone Column, Coconut Shell

1. INTRODUCTION

Construction industries are one of many contributors to Malaysia's economic and the development expenditure is 10.3 % increment for 11th Malaysia Plan (2016-2020). High consumption of natural resources in construction's activities caused various pollutions and environmental problems. For a better future, the world is looking at environmentally friendly development and greener materials for a sustainable environment. Aware of the scarcity of non-renewable natural resources, many researchers came out with various types of waste material as a substitute such as fly ash, bottom ash, slag, polyvinyl, coconut shell and many more. Coconut shell is one of the agricultural wastes and the demand toward coconut shell not as wide compared to coconut milk. Many coconut entrepreneurs faced problems in disposing of the coconut shells in a more efficient manner.

Recently, many studies were carried out to investigate the potential of coconut shell as an aggregate replacement [1,2,3]. Gludovatz, Walsh, Zimmermann, Naleway, Ritchie, and Kruzic [4] stated that coconut shell hard, woody shell, consist of cellulose, hemicellulose, and lignin. Gunasekaran, Annadurai, and Kumar [3] found out the coconut shell shows a better resistance against crushing and impact. Gunasekaran, Annadurai, and Kumar [3] also stated that coconut shell is more resistance against abrasion compared to natural aggregates.

Construction on soft ground area such as clay is a great challenge in the field of geotechnical engineering. The construction over soft clay soil increased due to lack of suitable land for infrastructures and other developments. According to Quaternary Geological Map of Malaysia, soft ground usually found in coastal plains of the country covers a large area of the west coast and east coast of Peninsular and East Malaysia [5]. In general practice, pile foundations are the famous choice to support the load. However, in some cases, the third method is more economical than deep foundation [6,7]. The third methods are mechanical compaction, dynamic compaction, vibroflotation, preloading, and sand or stone columns. Stone columns is a method where the portion of soil being replaced with granular material. Murthy [6] stated that the size of stones used for a stone column ranging from 6 mm to 40 mm and the columns was

placed 1 m to 3 m apart over the whole area. Fattah, Al-Neami, and Shamel Al-Suhaily, Marto, Hasan, Hyodo, and Makhtar, [7,8] stated that the stone columns can improve the bearing capacity, reduce settlement and accelerate the dissipation when being installed in cohesive soil.

The previous research on soft clay improvement was tested in small scale modeling and conducted in a laboratory. To understand the behavior of single stone column, it has been installed in soft clay, [8] and [9] used 10 mm and 16 mm represent 0.6 m to 1 m diameter in practice. There are many different lengths being used by researchers to study the shear strength of soft clay. Hasan, Marto, Hyodo, and Makhtar [10] stated that the value for 'critical column length' from past researchers occurred between 4 and 8 times the diameter of the column. Sexton, McCabe, Karstunen, and Sivasithamparam [11] presented the partially penetrating column gives a higher improvement in the undrained shear strength than the fully penetrating column with 13.51 % for 0.8 penetration ratio and decreased to 12.84 % for 1.0 penetration ratio. In laboratory tests, [9,12,13,14] used kaolin for production of repeatable homogenous soft clay samples in conducting Unconfined Compression Test (UCT) and to prepare multiple uniform samples.

Therefore, in this study, the strength of soft clay reinforced with crushed coconut shell as substitute material in the stone column had been investigated. The aim is to investigate the characteristic of coconut shell columns in improving the shear strength of soft clay. This study determines the effect of height penetration ratio (ratio of coconut shell column high, H_c, to a high of the sample, H_s) of a single crushed coconut shell columns on the strength characteristics. Result of soft clay reinforced with the crushed coconut shell column was greatly improved compared with unreinforced samples. Hence, using coconut shell as material in soft soil improvement, it will solve the disposal problem, besides, dependence on natural materials can be reduced.

2. MATERIALS AND METHODS

2.1 Materials

A number of tests have been conducted on crushed coconut shell (CCS), kaolin clay and kaolin clay reinforced with single CCS columns to investigate their physical and mechanical characteristics. Table 1 shows the summary of basic properties for coconut shell and kaolin clay used in this study.

Table 1 Basic properties of coconut shell and kaolin clay

Material	Test	Parameter	Value
Coconut shell	Soil Classification	AASHTO	A-2
	Standard Compaction	Optimum Moisture content	31.21%
		Maximum Dry Density	1.15 g/cm^3
	Small Pycnometer	Specific Gravity	1.70
	Relative Density	Minimum Density	0.548 g/cm^3
		Maximum Density	0.616 g/cm^3
	Constant Head Permeability	Coefficient of Permeability	2.32×10^{-12} m/s
Kaolin clay	Soil Classification	AASHTO	A-6
		USCS (Plasticity Chart)	ML
	Atterberg Limit	Plastic Limit	26%
		Liquid Limit	36%
		Plastic Index	10%
	Standard Compaction	Optimum Moisture Content	20.00%
		Maximum Dry Density	1.55 g/cm^3
	Small Pycnometer	Specific Gravity	2.62
	Falling Head Permeability	Coefficient of Permeability	4.81×10^{-12} m/s

2.2 Methods

2.2.1 Sample Preparation

The wasted coconut shell was collected from coconut milk shops and wet markets around Kuantan, Pahang, Malaysia. The cleaned coconut shell has been crushed manually with a hammer and to an obtained smaller size, a jaw crusher machine been used. The crushed coconut shell has been dried overnight at a temperature of 105–110ºC. After

drying, the shell has been graded by Dry Sieve Test similar to the aggregate grading process. The shell was passing through a 1.18 mm size of the sieve and retained on 0.6 mm were used in this study.

Kaolin clay "S300" was selected to prepare multiple uniform samples and produce homogenous soft clay samples for this study. To facilitate the process of forming, 20 % of water content was added to dry kaolin clay, which is the value of kaolin optimum moisture content. Both of the dry kaolin clay and distilled water was stirred vigorously by hand until it mixed uniformly.

To create one kaolin sample of 50 mm in diameter and 100 mm in height, about 312.4 g of wet kaolin was required to fill into the customized mold. The kaolin poured into three layers and each layer compacted with 5 freefall blows by customized steel extruder. Fig.1 shows the mold to prepare a kaolin sample. All 16 samples included a control sample and samples reinforced with CCS been tested four times for accurate value.

In preparing for the installation of CCS column for the reinforced specimens, the holes for the installation of CCS column were drilled at the middle by using a drill bit of respective diameter. Drilling process made before the specimen was removed from the mold to avoid the expansion of the sample. Fig.2 represents the high of the drilled hole.

Fig.1 Customized steel mold
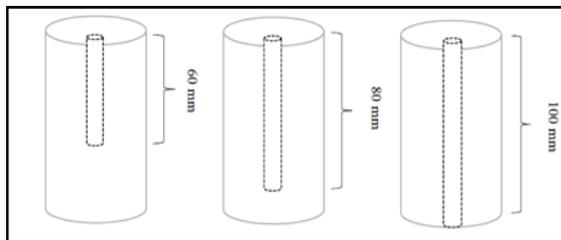
Fig.2 The high of a drilled hole

2.2.2 *Installation of single crushed coconut shell column*

In order to maintain a uniform density in each coconut shell columns, the mass of coconut shell was used to fill the pre-drilled hole based on the volume of the pre-drilled hole (as shown in Table 2). By referring to this method, the same density of 5.57×10^{-4} g/mm^3 had been produced for every specimen in this study.

CCS poured into 3 layers and each layer compacted with 27 blows by a small stick. After reinforcing the crushed coconut shell column, the mold was removed and ready to determine the shear strength. Fig.3(a) and Fig.3(b) showed the installation of CCS columns into the kaolin clay.

Each batch of kaolin sample contains the same penetration ratios (0.0, 0.6, 0.8 and 1.0). The columns diameter was 10 mm with an area displacement ratio of 4.0 %. Sample with variables of CCS installation was presented in Table 3.

Table 2 Detail on densification process for installing 10 mm diameter coconut shell columns in kaolin specimens

Column Length (mm)	Volume (mm^3)	Mass of Coconut Shell (g)	Density (g/mm^3)
60	4,714.29	2.63	5.57×10^{-4}
80	6,285.71	3.50	
100	7,857.14	4.38	

Fig.3 (a) Before installation of CCS column into the kaolin clay. (b) After installation of CCS column into the kaolin clay

Table 3 Sample with variables of CCS installation

Column Height Ratio (H_c/H_s)	Set			
	1	2	3	4
0	Sample 1	Sample 2	Sample 3	Sample 4
0.6	Sample 5	Sample 6	Sample 7	Sample 8
0.8	Sample 9	Sample 10	Sample 11	Sample 12
1.0	Sample 13	Sample 14	Sample 15	Sample 16

Note: H_c (column height), H_s (sample height)

2.2.3 *Unconfined Compression Test (UCT)*

This method is one of the fastest and cheapest

methods of measuring shear strength. The procedure of conducting unconfined compression test followed ASTM D 2166 and this method carried out only on saturated samples with no lateral support for the cylindrical specimens. The sample was placed in the loading machine between the lower and upper plates (Fig.4).

Fig.4 Sample has been tested

3. RESULTS AND DISCUSSIONS

All 16 samples were tested to identify the shear strength of the unreinforced kaolin and kaolin reinforced with CCS column by conducting the Unconfined Compression Test (UCT). With an area displacement ratio 4.0 % and column penetration ratio at 0.6, 0.8 and 1.0, four samples being tested for every penetration ratio to obtain the average and accurate value of shear strength.

3.1 Effect of CCS Column on Shear Strength

Naturally, all materials will be a strain when subjected to stress. The relation between stress and strain are derived on the basis of the elastic behavior of material bodies and its different for different material. This relation can be interpreted in the form of a graph of stress against strain.

The control sample was prepared without any reinforcement with CCS columns. A control sample was important in this study to investigate the effectiveness of the CCS columns method by comparing the obtained shear strength value. As reinforced kaolin, control sample has also been tested four times and calculated the average value of shear strength. The sample without the CCS columns was the control sample, which had a maximum shear strength of 18.27 kPa.

The average value of shear strength presents in Table 4 and Fig.5 shows the graph of the relationship between strain and stress for four sets of the control sample.

Table 5 shows a summary of the analysis of the Unconfined Compression Test (UCT). As shown in Table 5, the average shear strength for a sample of CCS column at 0.6 penetration ratio is 21.74 kPa with 19.02 % improvement compared to the unreinforced sample. For 0.8 penetration ratio, the average shear strength value is about 24.62 kPa and gives the 34.76 % of improvement. Lastly, for 1.0 penetration ratio, the average shear strength is 22.72 kPa with 24.34 % of improvement.

Fig.6, Fig.7, and Fig.8 respectively show the relationship between strain and stress for reinforced CCS column of 4.0 % displacement ratio at different penetration ratio that is 0.6, 0.8 and 1.0.

Table 4 Average value of shear strength for controlled sample

Sample	Strain (%)	Load, P (kN)	Stress, σ (kPa)
Sample 1	3.16	0.8320	20.50962
Sample 2	2.75	0.07200	17.82417
Sample 3	2.96	0.07200	17.78464
Sample 4	3.14	0.06880	16.96331
Average	3.0025	0.07400	18.27044

Table 5 Summary of analysis on UCT for 10 mm diameter column

Sample (UCT)	Column Height (mm)	Height Penetrating Ratio, H_c/H_s (%)	Max Shear Strength (kPa)	Improvement of Shear Strength (%)
Control Sample	0	0	18.27044	-
S10-60	60	0.6	21.74457	19.02
S10-80	80	0.8	24.62120	34.76
S10-100	100	1.0	22.71708	24.34

Note: S10-60 (Sample of 10 mm diameter, 60 mm of height), S10-80 (Sample of 10 mm diameter, 80 mm of height), S10-100 (Sample of 10 mm diameter, 100 mm of height),
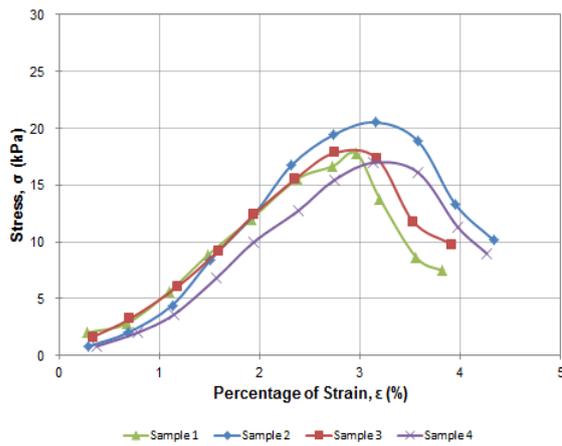
Fig.5 Relationship between strain and stress for controlled sample
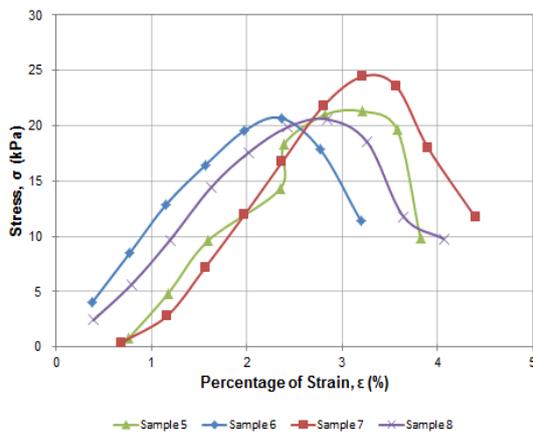
Fig.6 Relationship between strain and stress for a reinforced column of 10 mm diameter and 60 mm height.
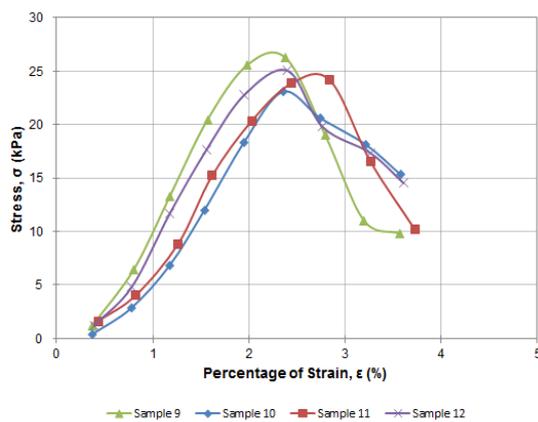
Fig.7 Relationship between strain and stress for a reinforced column of 10 mm diameter and 80 mm height.
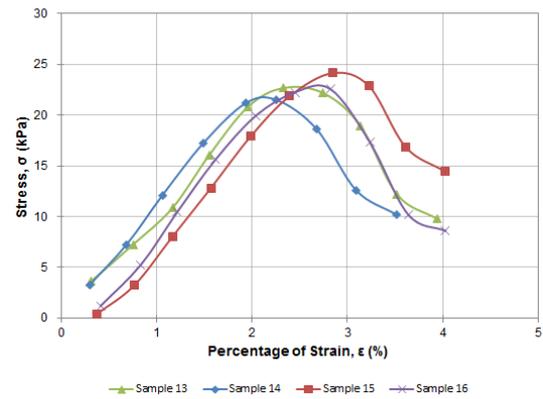
Fig.8 Relationship between strain and stress for a reinforced column of 10 mm diameter and 100 mm height.

3.2 The Effect of Column Penetration Ratio

Fig.9 presents the maximum shear strength versus column penetration ratio. Both increment of shear strength at 0.6 and 1.0 penetration ratio is over than 15 %. At 0.8 penetration ratio shows higher percentage over than 34 %. From the observation, the shear strength of reinforced CCS column increased at 0.6 and 0.8 penetration ratio, however, after fully penetration the shear strength decreased. The result has been obtained in this study support the idea of 'critical column length' where the column beyond this length will not improve the capacity of the clay [8].
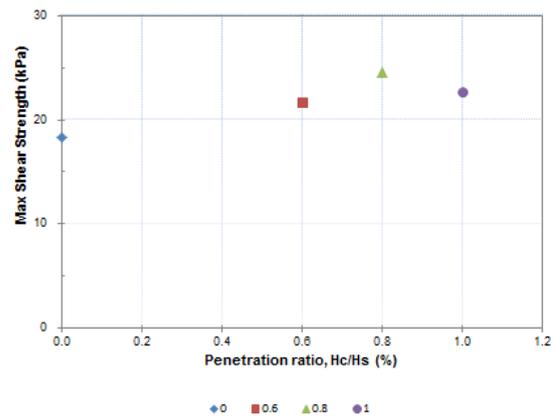
Fig.9 Maximum shear strength versus column penetration ratio, H_c/H_s

4. CONCLUSION

By the end of this research work, objectives were successfully achieved that are, to determine the physical and mechanical properties, as well as

the main focus, was to clarify the improvement in term of undrained shear strength of soft kaolin after reinforced with crushed coconut shell columns with different length of penetration. Based on laboratory test performed, the following conclusions can be drawn:

i.   Based from the Unified Soil Classification System (USCS) proved that kaolin can be characterized as ML, which indicates that kaolin was low plasticity silts based on its liquid limit and plasticity index of 36 % and 10 % respectively. Moreover, the result for the specific gravity of kaolin is 2.62 which in range for inorganic silt. The kaolin clay was classified as fine-grained soils which are 50 % or more passes No. 200 sieve. The kaolin clay was classified as clayey soil, A-6, based on AASHTO classification system. This means the materials usually have high volume changes between wet and dry states. In addition, from the compaction test, the result shows the maximum dry density, ($\rho_{d\,max}$) for kaolin is 1.55 kg/m^3 with optimum moisture content 20.0 %. Besides, the measured permeability coefficient of kaolin is 8.96 x 10^{-12} m/s.

ii. For coconut shell used in this study, it was found that the specific gravity is 1.70. From the result, coconut shell had low apparent specific gravity with an average value of 1.70, compared to natural soils with a specific gravity in the range of 2.5 to 2.7. With low specific gravity, the coconut shell provides the low bulk density and lighter in weight. According to AASTHO classification system, coconut shell fall under A-2-4 group and GI is zero for soils of groups A-2-4. This group includes a wide variety of granular materials, which are at the borderline between the materials falling in groups A-1 and A-3 and the silty – clay materials of group A-4 through A-7. It includes any materials, not more than 35 % of which passes sieve no. 200mm that cannot be classified as A-1 or A-3 because of having fines content or plasticity.

iii. The maximum dry density for coconut shell is 1.15 g/cm^3 and optimum moisture content is 31.21 %. While the value of the permeability coefficient of coconut shell is 2.32x10^{-3} m/s shows the value of the coefficient of permeability of coconut shell is larger compared to the value of kaolin. This shows a medium degree of permeability of coconut shell, representing a good drainage characteristic, and generally corresponding to clean sands. This means that the coconut shell is less permeable and good in discharge water. The relative density of coconut shell with 100 % compaction

and 0 % compaction can be determined as 0.616 g/cm^3 and 0.548 g/cm^3 respectively. For this study, 0.557 g/cm^3 been used to evaluate the mass of coconut shell needed in columns. The highest density cannot be applied because of the kaolin was very fragile and easy to disturbance due to the high compaction process.

iv. The installation of the single CCS column increased the shear strength of the soft clay, and the degree of improvement was influenced by the height penetration ratio. Through the unconfined compression test, the highest increment of shear strength occurred at 0.8 of column penetration. For the other column height, such as 60 mm and 100 mm, the result obtained showed that there was also have an improvement but less than 80 mm. The full penetration of the column, generate more voids inside the column, thereby causing more loose strength due to the lack of grip between CCS and kaolin. The UCT showed that there was a decreased improvement in the maximum column height and this was because of the manual excavation. More drilling process for the soft soil weakened the wall for the sample.

v.   The result obtained from this study support the 'critical column length' idea that is full penetration does not provide the maximum strength. The column length is greater than eight times the diameter no longer able to support the load capacity of soft cohesive clays. Hence, it can be concluded that high penetration ratio influenced the shear strength of the sample.

5. ACKNOWLEDGMENTS

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