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SHEAR STRENGTH OF SOFT CLAY REINFORCED WITH ENCASED LIME BOTTOM ASH COLUMN (ELBAC)

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ABSTRACT: Soft clay soils are problematic soil that causes bearing capacity failure and excessive settlement, leading to severe damage to buildings and foundation. In this study, bottom ash is used to replace the natural aggregate while quicklime is used to increase the bonding between bottom ash particles. This research is aimed to investigate the role of single encased lime bottom ash column (ELBAC) in improving the shear strength by using laboratory scale model. Kaolin is being used as soil sample while lime bottom ash as the reinforced column and the column is encased with non-woven geotextile. Laboratory tests are conducted to determine the physical properties of bottom ash, kaolin clay, and quicklime sample. Unconfined Compression Test (UCT) also used to test the shear strength of the reinforced kaolin samples. There are 21 kaolin samples being tested in this study and the dimension of the specimen used is 50mm in diameter and 100mm in height. However, there are two different types of the diameter of single lime bottom ash column being used which are 10mm and 16mm. The heights of the column are 60mm, 80mm and 100mm. The improvement of shear strength of single encapsulated lime bottom ash column with area replacement ratio of 4.00% (10mm column diameter) and 10.24% (16mm column diameter) are 43.58%, 50.00%, 49.17% and 38.08%, 42.67%, 32.75% at sample penetration ratio, H_C/H_S of 0.6, 0.8 and 1.0 respectively. It can be concluded that the shear strength of soft clay could be improved by the installation of the single encapsulated lime bottom ash column

Keywords: Sand Column, Soft Clay, Sustainable Construction, and Single Encased Lime Bottom Ash Column

1. INTRODUCTION

Soft clay soils are the type of soil that composed of very fine particles and can impede the flow of water. Clay soils are commonly stiff in the dry state but heavy and sticky when saturated with water. The reduction in strength and stiffness of soft clays causes bearing capacity failure and excessive settlement, leading to severe damage to buildings and foundation [1]. Therefore, deep mixing method is used to improve the permeability, strength and deformation properties of the soil. This method mainly depends on increasing the stiffness of natural soil by adding a strengthening admixture material such as lime.

Granular columns are widely used to improve the performance of weak deposits in order to reduce foundation settlement and to increase load-bearing capacity [2]. The performance of granular columns depends entirely on the characteristics of the surrounding material.

The use of stone columns as a ground improvement technique in soft cohesive soils is increasingly being extended to sites with poorer conditions [3]. This is being achieved with the use of geosynthetic reinforcement which acts to provide additional lateral support to columns, preventing excessive bulging and column failure. Although the use of geotextile encasement has been investigated and implemented on numerous projects, research into complex reinforced behavior is ongoing. In addition, the concept of using other geosynthetic materials such as geogrid for columns, small-scale laboratory testing of model sand columns was undertaken. In conjunction with this, a numerical modeling study was undertaken to further understand the interaction between the geogrid, column material, and the surrounding soil. Particular emphasis was placed on comparing the behavior of partially encased columns to fully encased columns. To simply modeling, the side wall friction in the cell was considered negligible and no resistance was applied to the model boundary. The critical column length is the shortest column which can carry the ultimate load regardless of settlement [4]. [5] found from their model study that the load carrying capacity of the column increases up to L/D = 4.1, beyond which there is no increase in column capacity. [6] suggested a minimum L/D ratio of 4.5, which is required to develop the full limiting axial stress on the stone column. [7], [8] reported from their experimental study that the *L/D* ratio of minimum 6 is required to develop the full limiting axial stress on the column. [9] found out from their model study that the critical length to be 4–5 *D*; for example, beyond this length of the stone column, no significant increase in its capacity has been observed. [10] supports the hypothesis of a critical column length corresponding to about six column diameters.

Columns longer than critical length did not show further increase in load-carrying capacity, however, longer columns may be needed to control the settlements. Accordingly, rational decisions can be taken to tailor the design of stone column installations to achieve maximum performance at an optimum cost.

In this study, bottom ash not only used to improve the soft soil strength as it also can reduce the need to quarry rock, since bottom ash is used as a substitute for natural crushed rock. In addition, it can reduce the need to dispose of the product to landfill storage. Hence, using this material is more sustainable and environmentally friendly and avoids the use of natural resources such as sand and gravel. However, lime is used as a binder to increase the bonding between the bottom ash which able to enhance the shear strength of the soft soil. Lastly, the undrained shear strength of soft clay reinforced with single encapsulated lime bottom ash column is determined in order to prove the feasibility to implement lime bottom ash column in real construction. Thus, varies the type of laboratory tests need to be conduct based on British Standard (BS) or the American Society of Testing Material (ASTM). The purpose of this study is to investigate the undrained strength of soft clay reinforced with single encapsulated lime bottom ash column.

2. METHODOLOGY

Few tests are conducted toward a small-scale model of the bottom ash as granular column and kaolin as the soft clay by adding some lime as binder. Laboratory tests are conducted to determine the characteristics of lime, kaolin and bottom ash based on British Standard and American Society of Testing Material (ASTM). The model is 50mm in diameter and 100mm in height. All the experiments are carried out at Soil and Geotechnical Laboratory ofUniversity Malaysia Pahang. Table 1 shows a list of tests and standard used**.**

2.1 Installation of Single Encased Lime Bottom Ash Column

In preparing for the installation of ELBAC for the reinforced specimens, the holes for the installation of ELBAC were drilled using a drill bit of respective diameter with the specimens still inside the mold to prevent it from expanding. The lime and bottom ash are installing in the holes to achieve a relative density of 13.31%.

To maintain a uniform density in each ELBAC and maintain the lime at 6%, the mass of bottom ash and lime used to fill the pre-drilled hole had been based on the volume of the pre-drilled hole. By referring to this method, the same density of 8.15×10^{-4}g/mm3 had been produced for every specimen in this study.

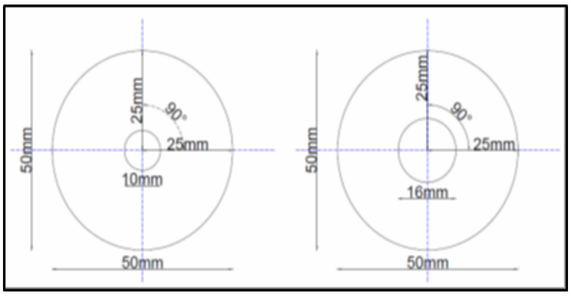

Fig. 1 Arrangement of the installed column in clay specimen

Table 1 List of tests and standard used

Materials	Tests	Standards
Kaolin	Hydrometer	BS 1377: Part 2 1990: 9.6
	Standard Compaction	BS 1377: Part 4 1990: 3.3
	Falling Head Permeability	ASTM D 2434
	Specific Gravity	BS 1377: Part 2: 1990: 8.3
	Atterberg Limit Liquid Limit Plastic Limit	BS 1377: Part 2: 1990: 4.3 BS 1377: Part 2: 1990: 5.3
Lime	Hydrometer	BS 1377: Part 2 1990: 9.6
	Specific Gravity	BS 1377: Part 2:1990: 8.3
	Atterberg Limit Liquid Limit Plastic Limit	BS 1377: Part 2:1990: 4.3 BS 1377: Part 2:1990: 5.3

Bottom Ash	Dry Sieve	BS 1377: Part 2: 1990: 9.3
	Specific Gravity	BS 1377: Part 2: 1990: 8.3
	Standard Compaction	BS 1377: Part 4: 1990: 3.3
	Constant Head Permeability	ASTM D 2434
Bottom Ash with Lime	Standard Compaction	BS 1377: Part 4 1990: 3.3
Soft Kaolin Clay Reinforced with Single Encapsulated (ELBAC)	Unconfined Compression Test (UCT)	ASTM D 2166

3. RESULT AND DISCUSSION

3.1 Physical and Mechanical Characteristics of Kaolin, Quicklime, and Bottom Ash

The physical properties of kaolin clay, quicklime, and bottom ash have been summarized in Table 2. The characteristic of kaolin is nearly the same as soft clay while bottom ash is almost similar to the natural aggregate like sand and fine gravel. In this study, quicklime able to increase the bonding between bottom ash particles based on its fine particle properties

Table 2 Physical and mechanical properties of kaolin, quicklime, and bottom ash

Test	Parameter	Kaolin	Lime	Bottom Ash
Soil Classification	AASHTO	A-6	A-7-5	A-1-a (0)
	USCS (Plasticity Chart)	MI	MV	-
Atterberg Limit	Plastic Limit (%)	26	72	-
	Liquid Limit (%)	36	61	-
	Plastic Index (%)	10	11	-
Standard Compaction	Optimum Moisture Content (%)	21	43	24
	Maximum Dry Density (Mg/m^3)	1.5	1.1	1.3
Small Pycnometer	Specific Gravity	2.6	2.3	2.3
Falling Head Permeability	Coefficient Permeability (m/sec) x 10^{-12}	9	-	-
Constant head Permeability	Coefficient of Permeability (m/sec) x 10^{-3}	-	-	5

3.2 Effect of Single Lime Bottom Ash Colum on Shear Strength

The shear strength of all the reinforced specimens is proved to be higher than the control sample. Meanwhile, the shear strength able to improve after installed the single encapsulate lime bottom ash column. Table 3 shows the shear strength results and its improvement

Fig. 2 and Fig. 3 show the correlation line for sample shear strength and improved shear strength of single encapsulated lime bottom ash column. From Fig. 2 the value of correlation cohesion, R^2 for diameter 10mm and 16mm are 0.9124 and 0.7443 respectively. Whereas, in Fig. 3 the R^2 for diameter 10mm and 16mm were 0.9255 and 0.6767, respectively. If the value of correlation cohesion, R^2 nearer to 1, this means the result is more accurate.

Table 3 Shear strength results and its improvement

Height Penetration Ratio, H_c/H_s	Shear Strength, S_u (kPa)			Average Shear Strength, S_u (kPa)	Improvement of Shear Strength, ΔS_u (%)
	1	2	3		
Controlled Sample					
0	11.6	12.4	12	1.0	-

Single Encapsulated Lime Bottom Ash Column (10mm)					
0.6	17.3	16.3	18.1	17.2	43.6
0.8	18.3	17.1	18.7	18.00	50.00
1.0	17.9	17.1	18.7	18	49.2
Single Encapsulated Lime Bottom Ash Column (16mm)					
0.6	17.4	16.7	15.5	16.6	38.1
0.8	17.1	17.5	16.7	17.1	42.7
1.0	16.4	15.9	15.5	15.9	32.8

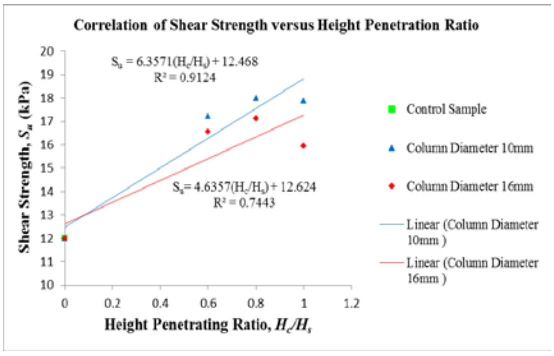

Fig. 2 Correlation graph of shear strength with height penetration ratio for single lime bottom ash column with diameter 10mm and 16mm

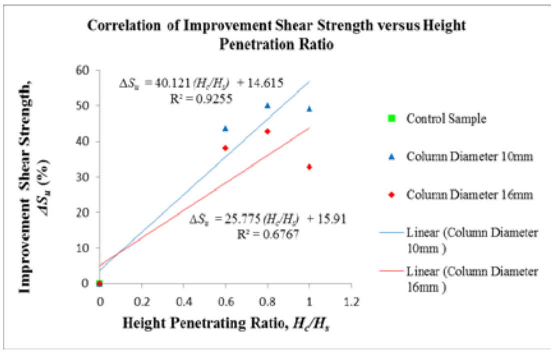

Fig. 3 Correlation graph of improvement shear strength with height penetration ratio for single ELBAC with diameter 10mm and 16mm

4. CONCLUSIONS

The major focus of this study is to check out whether there is any improvement on the undrained shear strength of soft kaolin soil after reinforced with single encapsulated lime bottom ash column with two different column diameters and different length of penetration. Based on laboratory test results analysis, the following conclusions can be made:

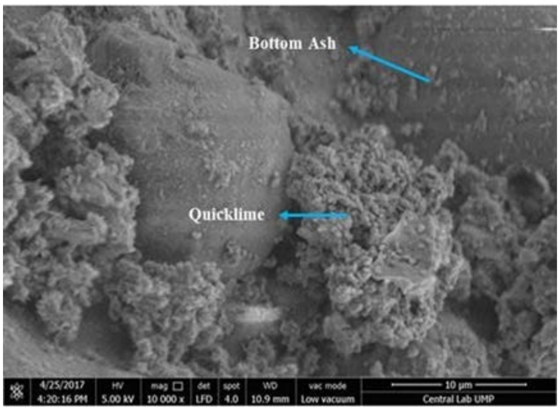

Fig. 4 Morphology images of lime bottom ash by SEM at a 10μm magnification

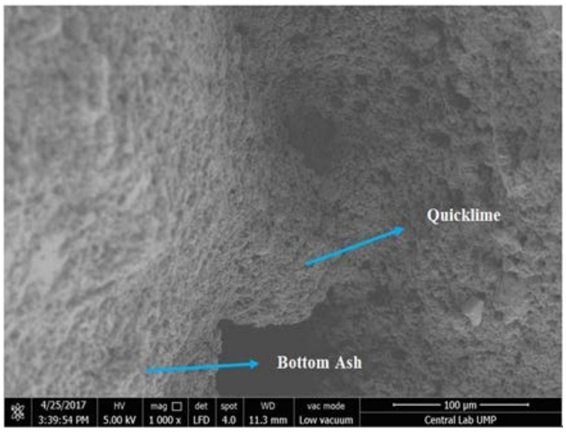

Fig. 5 Morphology images of lime bottom ash by SEM at a 100μm magnification

1. Kaolin characterized as MI by referred to Unified Soil Classification System (USCS) which indicates that it was medium plasticity silts based on its liquid limit (36%) and plasticity index (10%). The specific gravity of kaolin is 2.62 and it also classified as clayey soil, A-6, based on AASHTO classification system. This is because kaolin clay is well graded and its grain size is in the range between clay to fine silt. From the compaction test, the result shows that maximum dry density, $\rho d_{(max)}$ for kaolin is $1.53 Mg/m^3$ with the optimum moisture content of 20.91%. Other than that, the permeability coefficient of kaolin is 8.96 x 10−12m/s.

2. Tanjung Bin bottom ash that used in this study was categorized as A-1-a group which consisting predominantly of stone fragments or gravel, either with or without a well-graded binder

of fine material. The maximum dry density of bottom ash is 1.313Mg/m^3 while its optimum moisture content is 23.60% based on the result of the compaction test. Its specific gravity is 2.33. However, the permeability coefficient of bottom ash is 5.03 x 10^{-3}m/s which mean it has a good drainage characteristic that able to discharge water.

3. For quicklime, it characterized as by referred to the Unified Soil Classification System (USCS). From the result, it shows that its liquid limit is 71% while its plasticity index is 10% thus considered as low plasticity silt. Besides that, the specific gravity of quicklime is 2.26. According to the AASHTO classification system, this kaolin to be classified as clayey soil, A-7-5 which proved that it has moderate plasticity indexes in relation to liquid limit and may be highly elastic as well as subject to considerable volume change. Moreover, the maximum dry density for quicklime is 1.11Mg/m^3 with optimum moisture content 43%.

4. Installation of single encapsulated lime bottom ash column into kaolin soil can enhance the shear strength of the soft soil. For the result, it shows that with the installation of single encapsulated lime bottom ash column of diameter 10mm with penetration ratio H_c/H_s of 0.6, 0.8 and 1.0, it can increase the shear strength from 12kPa up to 17.23kPa, 18.00kPa and 17.90kPa respectively. However, for the single encapsulated lime bottom ash column of diameter 16mm with penetration ratio H_c/H_s of 0.6, 0.8 and 1.0, the shear strength increase from 12kPa up to 16.57kPa, 17.12kPa and 15.93kPa respectively.

5. In this study, the installation of a single encapsulated lime bottom ash column proved that it able to improve the shear strength of kaolin soil. Based on the test conducted, the installation of 10mm diameter of single encapsulated lime bottom ash column with an area replacement ratio of 4% can improve the shear strength of kaolin up to 43.58% 50.00% and 49.17% at sample penetration ratio, H_c/H_s of 0.6, 0.8 and 1.0 respectively. However, for the 16mm diameter of single encapsulated lime bottom ash column with an area replacement ratio of 10.24%, it can improve the shear strength up to 38.08%, 42.67% and 32.75% at sample penetration ratio, H_c/H_s of 0.6, 0.8 and 1.0 respectively. This shows that the improvement of shear strength does not fully rely on the column penetration ratio.

5. ACKNOWLEDGMENT

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