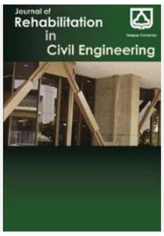

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Stabilization of Soft Clay Soil by the Reinforcement of Single Bottom Ash Silica Fume (BASF) Column

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ABSTRACT

This research examined the utilization of bottom ash mixed with silica fume in the ground improvement technique by constructing columns beneath the soft clay. Utilizing the bottom ash was an effective method and easily available in the market and the application of silica fume in the study improved the result through its pozzolanic characteristics. The vibro-replacement method was implemented during the bottom ash column installation process. The properties of the materials involved in the research were examined by suitable geotechnical tests complying with relevant standards. The important parameter, shear strength was accessed by conducting the Unconfined Compression Test (UCT). In this study, a total of seven (7) batches of soil samples were involved comprising the control sample. From each batch, it had five (5) soil samples which included the 14 mm and 20 mm diameter of column with the height of 60 mm, 80 mm, and 100 mm. From the results of shear strength improvement, the 14 mm diameter column with height penetrating ratios of 0.6, 0.8, and 1.0 were showing 58.97%, 88.56%, and 69.81% respectively. The next column design which had the 20 mm diameter with the height penetrating ratio of 0.8, recorded the highest improvement of 38.73%, followed by 1.0 and 0.6 which resulted in 32.81% and 19.19% respectively. The use of correlation technique had streamlined the complexity of the independent variables and verified the reliability of the results through the R^2 value. In summary, the improvement in shear strength was significantly influenced by the column design.

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1. Introduction

The process of urbanization has been rapidly escalating around the world. To cater the faster-growing population, urbanizing an area creates convenience to the society including the amenities, infrastructures, and shelter. As it comes to the 21st century, sustainability is the popular used terminology to emphasize that the sustainable development of cities is strongly intertwined with the future of humanity [1]. However, the forestation activity has caused the destruction of flora and fauna as well as the habitat of the animals. Similar to most of the developing countries around the world, Malaysia is one of the fastest-rising ASEAN countries in the region for its immense economic development [2], where it has been actively transforming the country into a first-world country and thus, the demand for land regardless of the soil conditions is expected to increase for the construction of mega projects. The current on-going mega infrastructure projects in Malaysia have been handled by the foreign infrastructure investment which includes East Cost Rail Link (ECRL), Malaysia-China Kuantan Industrial Park (MCKIP) as well as Bandar Malaysia [3]. Since the mega projects require a wide area of land, it is unavoidable that the project will cover not only land with proper soil conditions but also construction on soft clay land which requires systematic and detailed planning. In Malaysia, especially the east coast region that possesses abundant of soft soil which is required to undergo necessary soil treatment to alter its engineering properties to cater huge construction projects [4].

Kaolin clay also known as kaolinite has the general chemical formula $Al_2Si_2O_5(OH)_4$, which appears to be white or nearly white minerals when it is beneficiated or fired under a certain temperature [5]. Kaolin can be categorized in the group of kaolinite because it consists of the hydrated aluminum silicate crystalline mineral according to its general chemical formula [6]. Besides, natural clay is a sedimentary rock, formed from the finely grained natural soil from the parental or primary rock including igneous rock by the geological weathering process over a long period. From its physical appearance, the soft clay soil will turn into slurry form when mixed with water. Analyzing from its compressibility, the rate of compressibility is higher than the coarse-aggregate like sand and gravel that possesses a lower shear strength value [7]. Typical soft clay soil with moderate hardness will have a general value of undrained shear strength ranging from 0 to 50kPa [8], while the further study minimizes the range to about 20 – 40kPa [9]. Besides, clay is popularly categorized as a poor soil by its strength, compressibility coefficient, soil particle dispersion as well as the higher risk of soil erosion issues because they are prone to structural problems if the soil is employed directly in the civil engineering applications [10,11].

With the existing modern and advanced ground improvement techniques, building a structure on the soft clay soil is no longer an issue regardless of the size of the project. One of the main focuses in geotechnical engineering is ground improvement, which the treatment methods are grouped into mechanical, biological, and chemical stabilization [12]. The mechanical treatment methods include the installation of coarse-aggregate material columns to resolve the issue of insufficient of clay shear strength, stiffness, soil-bearing capacity, and soil settlement [13]. The fundamental objective of constructing a stone column is to speed up the soil consolidation which saves time and the construction cost of huge structures such as embankments [14], however it is not a sustainable practice as it can deplete the natural resources of the Earth, and the destruction of flora and fauna. Due to the rapid developments from all over the world, the conservation of the environment is a great concern particularly the concept of sustainability. Thus, the concept has been encouraged in all fields such as the construction industry which can cause negative effects to the surroundings. Researchers around the world have been modifying the existing soil and ground improvement techniques to discover the potential replacement materials for upgrading the poor properties of soil [15]. The utilization of micropiles which filled with the coarse aggregate are commonly utilized to transfer the applied load effectively to the ground particularly for the reinforced concrete structures [16]. From the common filled materials in the micropiles, the materials such as plastic and industrial by-product, and recycled Polypropylene (PP) fibers have been proven to increase the soil's strength through the execution of the Consolidated-Undrained (CU) test [17].

One of the bottom ash factories in Malaysia, the Tanjong Bin coal-based power plant produced 1,620 tons of fly ash and 180 tons of bottom ash that ended up in ash ponds, and these figures are estimated to increase in the future [18]. From the analysis, the bottom ash supplied from this factory has a value of 641.03kg/m^3 in terms of its density as compared to the natural coarse aggregate which has an average value of 1227.83kg/m^3 [19]. Besides, the bottom ash and fly ash possess a lower value of density as compared to the conventional aggregates due to the higher carbon content which causes it to have a porous or vesicular structure. Coherent to that, the bottom ash which has the lower specific value which is excellent in absorbing water [18], has been utilized in upgrading the strength of concrete as well as the shear strength of soft clay soil [20,21]. Thus, the replacement of the industrial by-products in producing granular columns can subsequently resolve the waste issue and conserve the environment.

As of now, the better strength improvement of kaolin clay soil using bottom ash is achieved by adding the silica fume due to its fine particles ranging from 0.1 to 0.5 µm [22]. From the data, the smaller the particle size, the higher the water absorption rate. Silica fume is also called as microsilica due to its natural behavior, acting as an extremely fine non-crystalline silica which is the by-product of the elemental silicon. Silica fume is classified as a supplementary cementitious material that acts as a filler, improving the physical structure by filling up the voids between the cement particles with the appropriate amount [23]. Furthermore, the chemical properties of silica fume that comprises of more than 85% of silica fume makes it a reactive material, and capable to dissolve in liquid through the pozzolanic reaction. Hence, silica fume which contains the abundant amount of amorphous silica causes the material to be capable in substituting the coarse aggregate directly to the sample without additional process for instance curing of specimen [24].

Consequently, the current investigation focused on the filling of column with the bottom ash and silica fume to alter the soil's strength within the small-scale laboratory test, and the authors had maximized the accuracy of results by ensuring that the good workmanship during the BASF column preparation process. In light of the previous data, there are myriad of existing studies to identify the utilization of bottom ash mixed with silica fume as the substitute material in the improvement of concrete and soil. The combination of these two materials was expected to upgrade the parameters such as reducing the maximum dry density (MDD) value, upgrading the permeability coefficient, increasing the optimum moisture content (OMC), and reducing the specific gravity. Therefore, this paper concentrated on the approach of the bottom ash mixed with silica fume made column which examined via the UCT machine. Furthermore, this study was significant in stretching out the capability of the BASF column in treating the weak kaolin clay soil through the rectification of the engineering properties. Coherent to that, we hypothesized that (1) the utilization of the BASF column can alter the physical and mechanical properties of the kaolin clay; and (2) the utilization of the BASF column can upgrade the shear strength of the kaolin clay.

2. Methodology

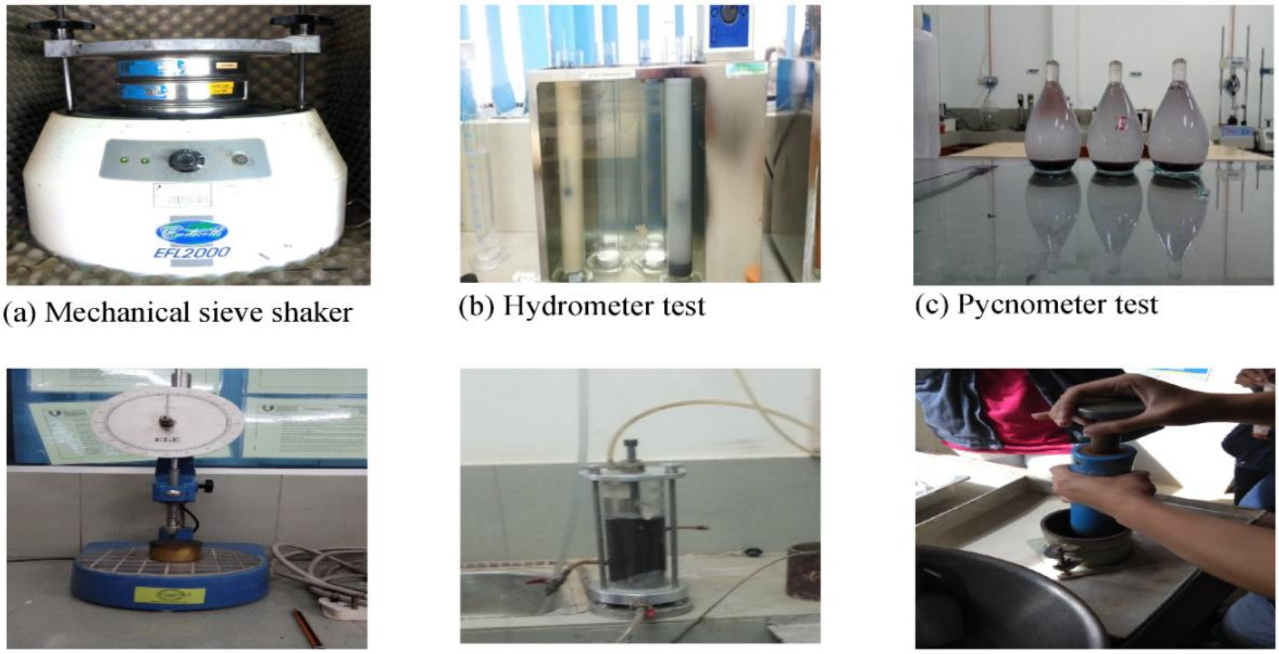
It discussed about the entire process of the laboratory works throughout the study. The related geotechnical works were conducted based on the British Standard (BS) and American Society of Testing Material (ASTM). The beginning of the study was focused on the purchase of the materials, followed by the laboratory works for the determination of the materials properties. By knowing their properties, the work was proceeded with the column preparation.

2.1. Experimental materials and processes

The first part of this study was to determine the particle size distribution (PSD) of the bottom ash through the dry sieve test by following BS 1377: Part 2: 1990: 9. About 500g of the sample was used and shaken in the mechanical sieve shaker in Figure 1(a) for 10 minutes. The retained sample on each sieve size was weighted and a PSD curve was drawn accordingly. For kaolin clay and silica fume, the hydrometer test was executed following ASTM D 422: 1998 by using 50g of the soil which passes through the 63 µm sieve, transferring it into a 1000 ml volume of sedimentation cylinder before it was immersed in the water bath as shown in Figure 1(b). This process was conducted for 48 hours to obtain accurate results by taking the readings of the hydrometer at the respective time.

For the analysis of specific gravity, it was conducted for all the materials in this study in accordance to BS 1377: Part 2: 1990: 8, and each test used about 5 – 10g of sample that passed through the 2 mm sieve. The materials were poured into the density bottle as shown in Figure 1(c). Besides, the Liquid Limit and Plastic limit test were executed following BS 1377: Part 2: 1990:4 and BS 1377: Part 2: 1990: 5 respectively. About 500g of sample that passed through the 425 sieve µm was prepared. Figure 1(d) showed the cone penetration test. The coefficient of permeability or hydraulic conductivity was accessed by conducting the falling and constant head test in accordance to ASTM D 2434 which it was for fine (kaolin and silica fume) that had the permeability value less than 1 x 10^{-4} m/s, while coarse aggregate (bottom ash) had the permeability value more than 1 x 10^{-4} m/s than as depicted in Figure 1(e).

Before proceeding to the BASF column preparation, the execution of proctor test in accordance to BS 1377: Part 4: 1990: 3.3 was to access the MDD and OMC by using 3-4 kg of oven-dried sample. The compaction process was done by free-falling 25 blows of the 2.5kg hammer to minimize the air voids inside the sample in Figure 1(f).



(a) Mechanical sieve shaker (b) Hydrometer test (c) Pycnometer test

(d) Cone penetration test (e) Permeability test (f) Proctor test

Fig. 1. Laboratory works for the determination of the material properties (a) Sieve analysis (b) Hydrometer test (c) Pycnometer test (d) Cone penetration test (e) Permeability test (f) Proctor test.

2.2. Experimental materials and processes for the BASF column

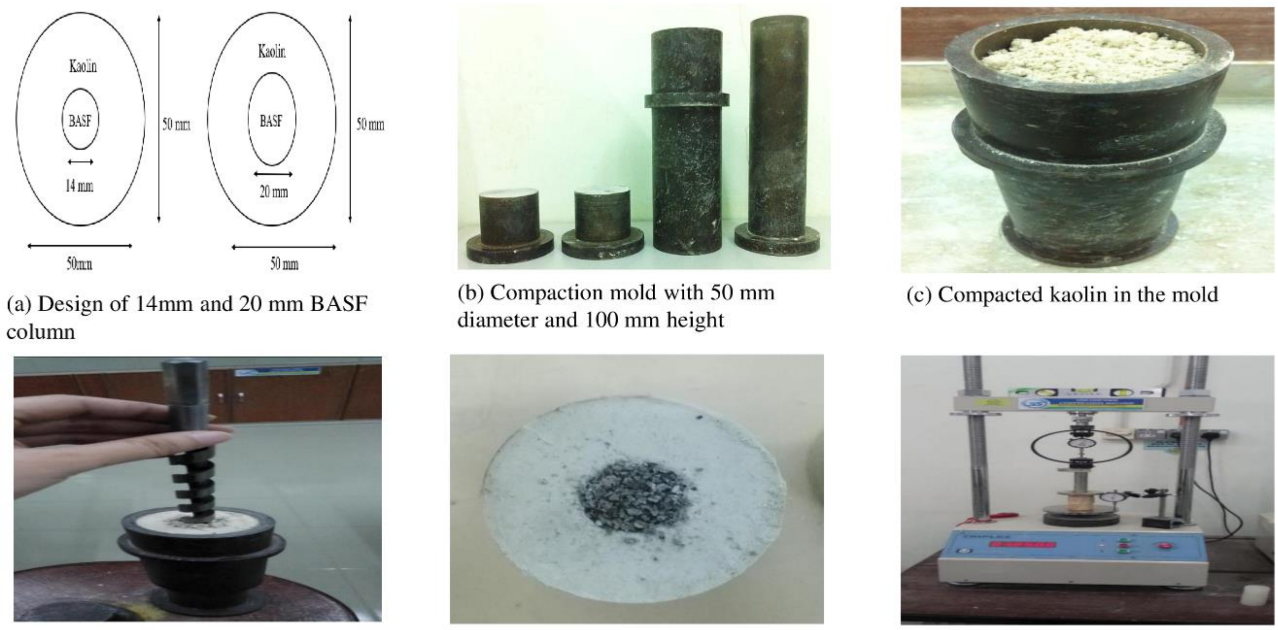
The flowchart of the experimental works for the BASF column was shown in Figure 2. The preliminary work followed the design of the column as depicted in Figure 2(a), which the silica fume bottom ash acted as the reinforcement with no geotextile encapsulation. From Table 1, it showed the details of the bottom ash silica fume column. The table included the column parameters values such as the Column Penetrating Ratio (H_c/H_s), Height over Diameter of Column Ratio (H_c/D_c) and Volume Replacement Ratio (V_c/V_s). For this study, it had a total of seven (7) batches of specimens where each batch had five (5) samples. These batches comprised the control samples, and the design of 14 mm with 20 mm diameter BASF column, and with the height of 60 mm, 80 mm, and 100 mm. The 60 mm and 80 mm were classified as the partial penetrating columns while the 100 mm was categorized as the fully penetrating columns.

Table 1. Design of bottom ash silica fume column in accordance to column parameters.

Design	Diameter (mm)	Height (mm)	V_c/V_s	H_c/H_s	H_c/D_c
S1460		60	0.0470	0.6	4.2857
S1480	14	80	0.0627	0.8	5.7143
S14100		100	0.0784	1.0	7.1429
S2060		60	0.0960	0.6	3.0000
S2080	20	80	0.1280	0.8	4.0000
S20100		100	0.1600	1.0	5.0000

*S1460 indicates single column with 14 mm column diameter and 60 mm column height

The utilization of bottom ash and silica fumes acted as the marginal site agent by stabilizing the subgrades. Before that, the kaolin clay S300 with 17.5% moisture content was applied for the BASF column preparation process as determined from the standard compaction curve as shown in Figure 4(a). After the mixing process, the kaolin was transferred into the compaction mold with the respective dimension in Figure 2(b), and it was further compacted with three layers in Figure 2(c). The hole was created with the respective diameters, 14 mm and 20 mm. It was created by drilling bits up to the height of 60 mm, 80 mm as well as 100 mm on the prepared soft clay specimen as shown in Figure 2(d). The backside of the drilling bits was used to hit the pouring materials for three (3) layers by applying a free fall of five (5) blows to ensure minimum or no air trapped inside. The raining method was applied for the pouring process of bottom ash and silica fume to ensure the homogeneity of column produced as demonstrated in Figure 2(e). After the columns were prepared, the flow of work was continued to the analysis of shear strength parameters by the UCT in Figure 2(f). The demonstration of UCT was done by observing the condition of the column and the test was terminated if failure occurred such as bulging of column.



(a) Design of 14mm and 20 mm BASF column

(b) Compaction mold with 50 mm diameter and 100 mm height

(c) Compacted kaolin in the mold

(d) Drilling process on the prepared kaolin specimen

(e) BASF column was prepared

(f) on-going process of UCT

Fig. 2. Flowchart for the BASF column Compaction mold (a) Design of BASF 14 mm and 20 mm column (b) Compaction mold with 50 mm diameter and 100 mm height (c) Compacted kaolin in the mold (d) Drilling process on the prepared kaolin specimen (e) Silica fume column is prepared (f) on-going process of UCT.

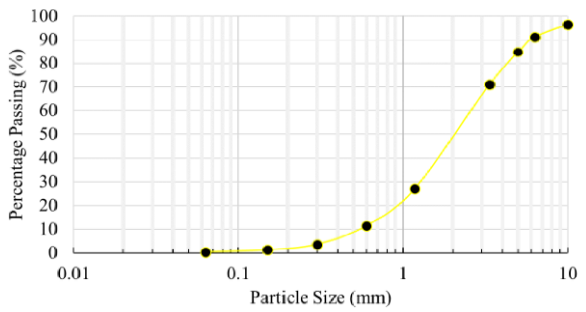
3. Results and discussion

This topic revealed the analysis result obtained from the conducted geotechnical tests. It had shown that the substituted material, bottom ash mixed with silica fume had the similar properties like coarse aggregate

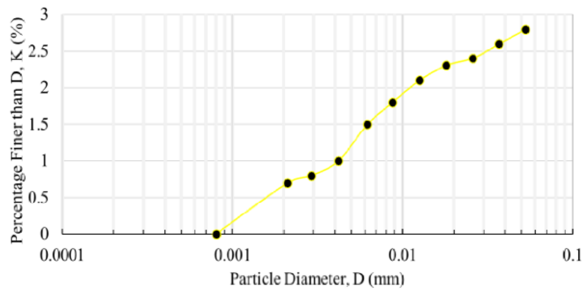
3.1. Material properties

Table 2, 3, 4 and 5 showed the properties of materials used in the study.

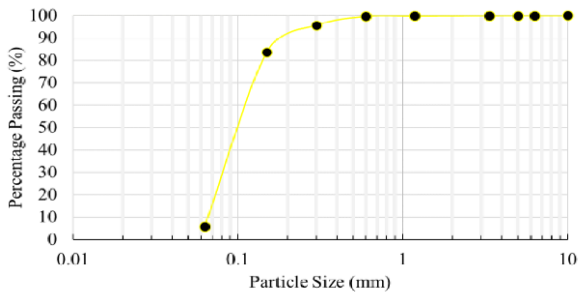
From Figure 3, it showed the PSD of the materials used in the study. The materials were well-graded as the majority amounts of particle retained on the specific size. For kaolin clay, the majority particle size of kaolin clay was retained at 0.01 mm in Figure 3(a) while for the bottom ash, it had the major amount of 1.18 mm as depicted in Figure 3(b). The particle size of silica fume lied within 0.0004 – 0.052 mm as shown in Figure 3(c).



(a) Particle size distribution of kaolin clay S300



(b) Particle size distribution of bottom ash

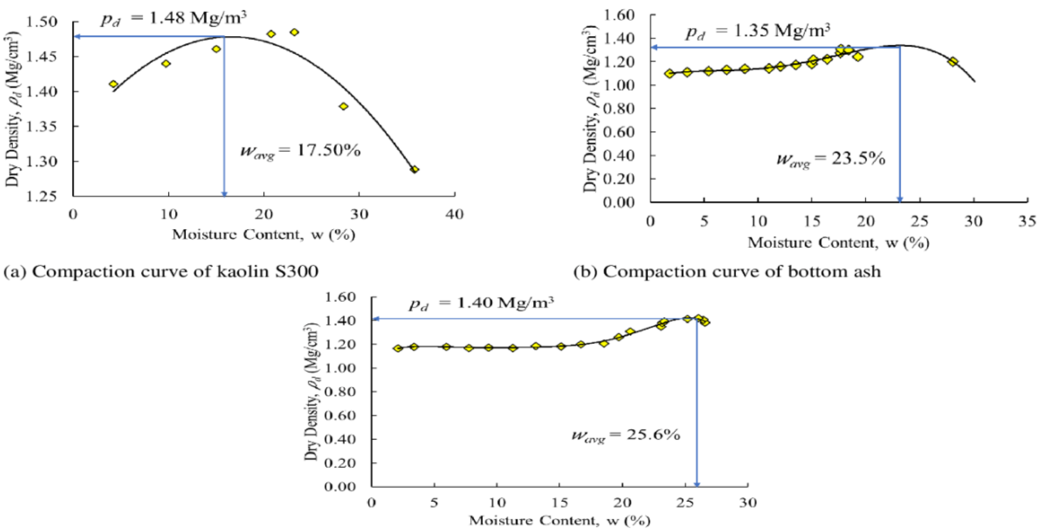


(c) Particle size distribution of silica fume

Fig. 3. Particle size distribution curve (a) Particle size distribution of kaolin clay S300 (b) Particle size distribution of bottom ash (c) Particle size distribution of silica fume.

The Atterberg Limit test was conducted for kaolin clay, bottom ash as well and the silica fume which the Plasticity Index was 10.00%, 9.70%, and 10.10% respectively. According to the Unified Soil Classification System (USCS), kaolin clay had the result of CL which was a low to medium plasticity clay while the bottom ash fell under the category of well-graded sand, SW. The silica fume fell in the category of SM category which was a sand-silt mixture and the findings were supported by the previous data [25]. From the ASSTHO, the kaolin clay had A-6 which was classified as a clayey soil while for the bottom ash and silica fume were both under the group of silty or clayey gravel mineral. Since it was a low permeability substance for kaolin clay and silica fume, the falling head test was conducted and the permeability value obtained was 1.97 x 10^{-12} m/s and 1.18 x 10^{-10} m/s respectively, which met the standard of low permeability of soil. The bottom ash was a granular-like material and this behavior was proven through the permeability study using the constant head test, recorded 5.02 x 10^{-3} m/s. This value indicated that the bottom ash had the characteristic of good drainage to discharge excessive water from the soft kaolin clay, further reducing the pore water pressure.

The raw kaolin clay S300 showed the OMM of 17.50% with MDD of 1.48 Mg/m^3 in Figure 4(a). For the substitute material which was bottom ash, the recorded OMM was 23.50% with a MDD of 1.35 Mg/m^3. The OMM value was notified to increase to 25.60% after the addition of 6.00% of silica fume, increasing the MDD to 1.40 Mg/m^3 due to the increment of water content as shown in Figure 4(b) and Figure 4(c). The specific gravity of bottom ash was 2.21, which was a standard quality because of the low quality of bottom ash that can record the specific gravity lower than 2. The phenomena can be explained by its low iron oxide content within the soil itself.



(a) Compaction curve of kaolin S300 (b) Compaction curve of bottom ash

(c) Compaction curve of bottom ash mixed with 6% of silica fume

Fig. 4. Compaction curve (a) Compaction curve of kaolin S300 (b) Compaction curve of bottom ash (c) Compaction curve of bottom ash mixed with 6% of silica fume.

Table 2. Kaolin clay S300 properties.

Material	Test	Parameter	Result
Kaolin Clay	Soil Classification	USCS (Plasticity Chart)	CL
		AASHTO	A-6
	Small Pycnometer	Specific Gravity, G_s	2.64
	Atterberg Limit	Plastic Limit, W_P (%)	24.40
		Liquid Limit, W_L (%)	34.40
		Plastic Index, I_P (%)	10.00
	Standard Compaction	Optimum Moisture Content, w_{opt} (%)	17.50
		Maximum Dry Density, $\rho_{d(max)}$ (Mg/m^3)	1.48
	Falling Head	Coefficient of Permeability, k (m/s)	1.97x10^{-12}

Table 3. Bottom ash properties.

Material	Test	Parameter	Result
Bottom Ash	Soil Classification	USCS	SW
		AASHTO	A-2-5
		Particle Size Range (mm)	2 to 0.063
	Small Pycnometer	Specific Gravity, G_s	2.21
	Atterberg Limit	Plastic Limit, W_P (%)	54.31
		Liquid Limit, W_L (%)	64.00
		Plastic Index, I_P (%)	9.70
	Standard Compaction	Optimum Moisture Content, w_{opt} (%)	23.50
		Maximum Dry Density, $\rho_{d(max)}$ (Mg/m^3)	1.35
	Constant Head	Coefficient of Permeability, k (m/s)	5.02 x10^{-3}

Table 4. Silica fume properties.

Material	Test	Parameter	Result
Silica Fume	Soil Classification	USCS (Plasticity Chart)	SM - MH
		AASHTO	A-2-7
	Small Pycnometer	Specific Gravity, G_s	2.27
	Atterberg Limit	Plastic Limit, W_P (%)	80.45
		Liquid Limit, W_L (%)	90.50
		Plastic Index, I_P (%)	10.10
	Standard Compaction	Optimum Moisture Content, w_{opt} (%)	65.00
		Maximum Dry Density, $\rho_{d(max)}$ (Mg/m^3)	0.79
	Falling Head	Coefficient of Permeability, k (m/s)	1.18x10^{-10}

Table 5. Bottom ash + 6% silica fume properties.

Material	Test	Parameter	Result
Silica Fume	Standard Compaction	Optimum Moisture Content, w_{opt} (%)	25.60
		Maximum Dry Density, $\rho_{d(max)}$ (Mg/m^3)	1.35
	Constant Head	Coefficient of Permeability, k (m/s)	3.12 x 10^{-5}

3.2. Shear strength parameters

From the UCT, related results regarding the shear strength parameters were obtained such as the shear strength and shear strength improvement. Each batch consisted of five (5) specimens with different heights, 60 mm, 80 mm, and 100 mm making them different in height penetrating ratio. The results obtained from the UCT were demonstrated in Table 6. From Table 6, it was noticed that the highest shear strength improvement occurred when the height was 80 mm for both diameters, 14 mm and 20 mm. The result can be explained by the optimum amount of silica fume was substituted into the BASF column which possessed the cementitious properties. It improved the stiffness of the specimen when the cementitious material was increased [26]. Furthermore, a similar trend was recorded for both 14 mm and 20 mm diameter of BASF column, which an increasing trend of shear strength was noticed up to 80 mm height, and the shear strength recorded a reduction when the 100 mm height of BASF column was examined. The data was supported by the previous result as the effectiveness of treatment declines when the coarse-material increases [27]. Hence, the results suggested that the critical height was 0.8 in this study.

Table 6. The result of shear strength and its improvement.

Design	V_c/V_s	H_c/H_s	H_c/D_c	S_u (kPa)	ΔS_u (%)
Control	0	0	0	12.747	-
S1460	0.0470	0.6	4.2857	20.264	58.97
S1480	0.0627	0.8	5.7143	24.039	88.59
S14100	0.0784	1.0	7.1429	21.646	69.81
S2060	0.0960	0.6	3.0000	15.193	19.19
S2080	0.1280	0.8	4.0000	17.684	38.73
S20100	0.1600	1.0	5.0000	16.929	32.81

3.2.1. Correlation of shear strength improvement against column penetrating ratio

From Table 6, the column penetrating ratio of 0.8 resulted in the highest improvement of kaolin shear strength, recorded 88.56% with a diameter of 14 mm and 80 mm of height. At 0.8 H_c/H_s, the load transference was effective from the UCT machine which was then converted into the certain magnitude of axial loading, where the reinforced part had predominantly transferred the load to the unreinforced bottom part of the BASF column. From the previous study, the researchers proposed that the optimal column length shows a significant effect towards the entire performance of column regardless the type of filled materials [16]. From the same column diameter, the second and third highest improvement were recorded at 69.81 % and 58.97% with the value of 1.0 and 0.6 respectively. These columns were showing lesser improvement rate as compared to 0.8 H_c/H_s which can be categorized as the ineffectiveness of load transference within the column itself. Furthermore, the BASF column which had a diameter of 20 mm with a 0.6 H_c/H_s recorded the least improvement, 19.19%. Furthermore, the same diameter with the values of 0.8 and 1.0 recorded 38.73% and 32.81% improvement respectively. This column category showed a similar trend like the 14 mm column where the highest improvement occurred at 0.8 and hence, this study suggested that the optimum value of H_c/H_s was 0.8. From Figure 5, the correlations between these parameters concerning its diameter design were determined through equation (1), R^2= 0.8481, and R^2=0.8770 for equation (2), by utilizing the control specimen as the reference, delivering the relationship between a set of dependent and independent variable by statistical approach [28].

$$\Delta Su = 81.504(H_c/H_s) + 5.4399 \tag{1}$$

$$\Delta Su = 37.266(H_c/H_s) + 0.3219 \tag{2}$$

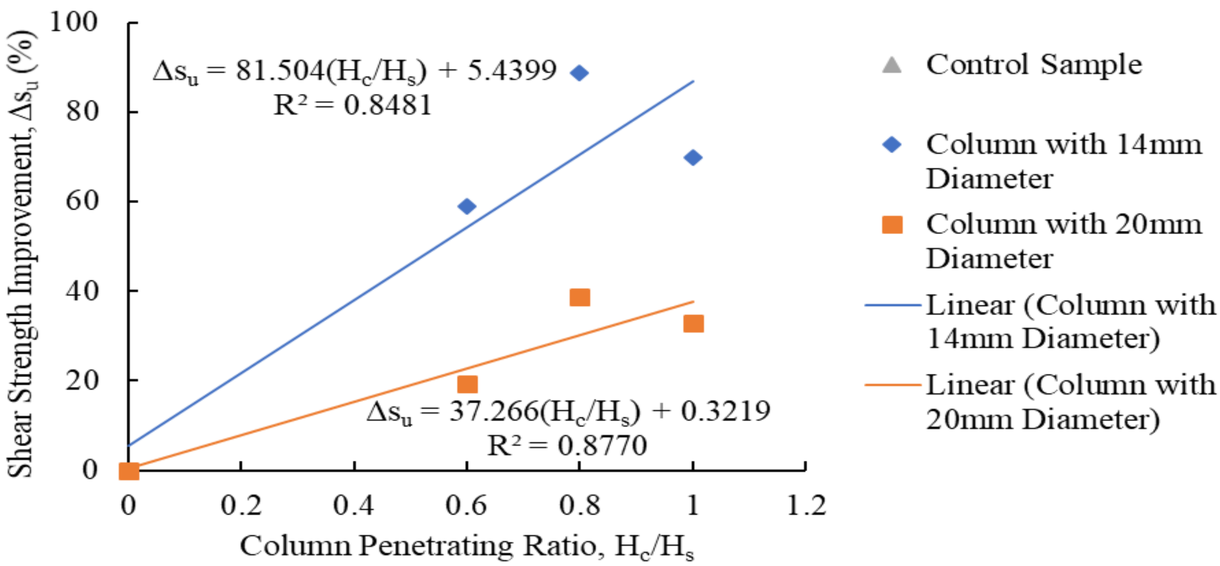


Fig. 5. Correlation of Shear Strength Improvement versus Column Penetrating Ratio.

3.2.2. Correlation of shear strength improvement against height over diameter of column ratio

The highest value of H_c/D_c was 7.1429 and the smallest was 3, both values resulted in 69.81% and 19.19% shear strength improvement based on the control sample. The previous studies had concluded that the preferable value of H_c/D_c value fell in the range of 4 – 6 times [29]. While in this study it was proven that the highest improvement occurred at the value of 5.7143, which was within the range and the value was obtained from the category of 14 mm diameter BASF column. Coherent to that, the value of 4 H_c/D_c recorded the highest improvement in the category of 20 mm BASF column, which complied with the proposed value. A similar value was also proposed by other researchers which stated the critical column length lies within 4 to 8 times to its column diameter [30]. Therefore, the study noticed that the failure of column such as bulging and swelling of column was prolonged for the BASF columns which possessed the proposed value of 4 – 6 times as stated by the previous researchers. Similarly, this phenomena was described as the reduction of soil swelling pressure with the addition of the nanoparticles, which was silica fume in the study [31]. Equation (3) and (4) showed the relationship of the respective parameters with R^2=0.8480 and R^2=0.8770 as shown in Figure 6.

$$\Delta Su = 11.416(H_c/D_c) + 5.4249 \quad (3)$$

$$\Delta Su = 7.4533(H_c/D_c) + 0.3219 \quad (4)$$

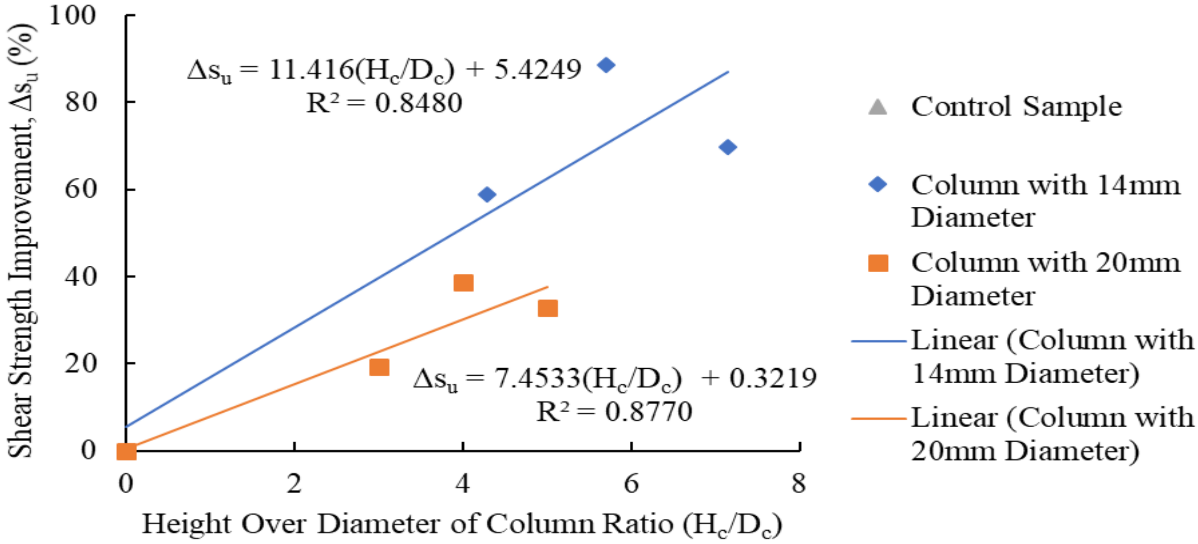


Fig. 6. Correlation of Shear Strength Improvement versus Height Over Diameter of Column Ratio.

3.2.3. Correlation of shear strength improvement against volume replacement ratio

Based on Figure 7, the highest value of V_c/V_s was 0.16, produced the improvement of 32.81% while the largest shear strength improvement occurred when the value was 0.0627 giving the 88.56% improvement. It was noticed that the largest value of volume replacement did not directly produce the largest value of shear strength improvement as the original state of soil was disturbed during the preparation process. The use of 14 mm and 20 mm drilling bits caused the surrounding soil to loosen although the optimum compaction effort had been done beforehand. This statement was supported by the previous data mentioned that the shear strength of soil can be reduced by the external forces imposed to the respective area [32]. Besides, the value of 0.096 V_c/V_s produced the lowest shear strength improvement with only 19.19%, which can be classified as the insufficient of reinforcement to cater the axial loading and the soil disturbance effect was not cancelled. The result was similar to the study using the higher amount of fiber which interfered the consistency and homogeneity of the specimen [27]. The regression equations (5) and (6) showed the correlation between the parameters, having R^2= 0.8536 and R^2 = 0.8770 as referred to Figure 7.

$$\Delta Su = 1045.4(V_c/V_s) + 5.2082 \quad (5)$$

$$\Delta Su = 232.92(V_c/V_s) + 0.3219 \quad (6)$$

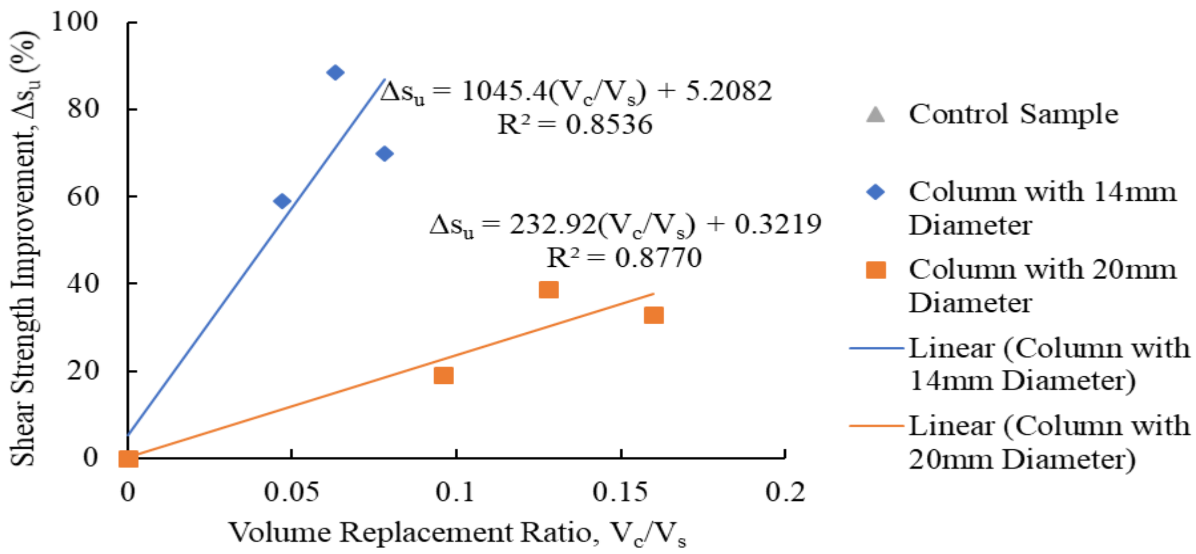


Fig. 7. Correlation of Shear Strength Improvement versus Volume Replacement Ratio.

4. Conclusion

The findings of this research by utilizing the bottom ash mixed with silica fume as the reinforcement material for the construction of granular column in upgrading the shear strength of kaolin clay were briefly summarized as follows;

- From the properties of materials as recorded in Tables 2,3,4,5 and 6, kaolin clay was a poorly graded silty soil with a low permeability value. The combination of bottom ash with silica fume had produced a mixture that showed a higher permeability value, which was able to resolve the issue of water accumulation due to the nature of engineering properties.
- The 14 mm BASF column category showed the shear strength improvement rate between 58.97% to 88.59% whereas the 16 mm BASF column category only recorded the value from 19.19% to 38.73%. The results were classified as the larger diameter that caused the shear strength to reduce [33,34]. From the results, the performance of the BASF column was reflected in terms of the column parameters which the optimum value of H_c/H_s, H_c/D_c and V_c/V_s were 0.8, 5.7413 and 0.0627 respectively.
- The use of correlation techniques in correlating the shear strength parameters with the column ratio simplified the complex engineering variables in a simple linear equation, proved that the results were accurate and reliable based on the R^2 value, which were more than 0.5.

4.1. Recommendation

From the study, it was proven that the replacement of coarse aggregate using bottom ash mixed with silica fume produced a better shear strength improvement via the UCT. However, there were certain limitations detected and several recommendations to be proposed for future investigation and they were as follows;

- Similar study can be conducted using the same BASF column design, however with the different coarse material mixed with silica fume.
- Further study is required to analyze the optimum percentage of silica fume to suit the different designs of the BASF column. The number of BASF column can be increased and installed within the same size of kaolin specimen.

- The results can be used to compare with the actual construction site results as the constructed specimens were designed and assumed to be homogeneous throughout the study. During the preparation process, the small change and human errors were neglected.

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