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INFLUENCE OF CRUSHED BRICK COLUMNS ON GEOTECHNICAL PROPERTIES OF EXPANSIVE SOIL

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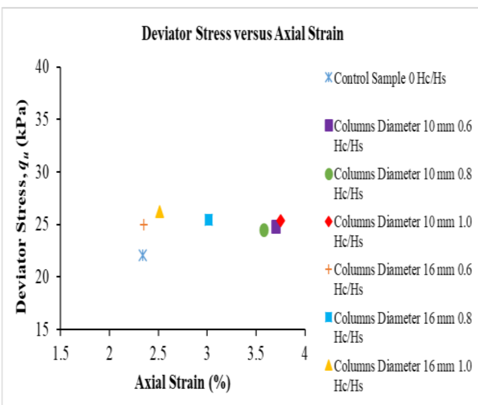
Graphical abstract



Abstract

Utilization of crushed brick which is a common industrial material that is potentially wasted during the construction process in ground improvement can relieve its detrimental effects on the environment thereby reducing the waste disposal challenges. Hence, this study proposes its utilization as reinforcement to the soft clay soil. The tests mainly focused on the particle size distribution (PSD), specific gravity, Atterberg limit, proctor analysis as well as the shear strength parameters from Unconfined Compression Test (UCT). Coherently, the vibro-replacement method was deployed within a small-scale laboratory approach as a prediction model for the construction of a group of crushed brick columns. The column design was mainly classified into partially penetrated columns which have 60 mm and 80 mm height, and fully penetrated columns with 100 mm height. The mass of crushed brick used was approximately 1.07% - 4.56% of its total mass of specimen which produces the shear strength improvement rate from 11.00% - 18.55%. From the obtained results, the use of fully penetrated 100 mm diameter columns enhanced the undrained shear strength of kaolin clay to the maximum value, 26.20kPa or 18.55% as compared to the control sample with no reinforcement, which reduced the soil settlement and promoted the use of sustainable material in ground improvement.

Keywords: Expansive clay, brick, shear strength, ground improvement, foundation

Abstrak

Penggunaan bata hancur yang merupakan bahan industri biasa yang berpotensi terbuang semasa proses pembinaan dalam pembaikan tanah dapat mengurangkan impak buruk persekitaran dan dengan itu mengurangkan cabaran pelupusan sisa. Oleh itu, kajian ini mencadangkan penggunaannya sebagai pengukuhan kepada tanah liat lembut. Kajian ini fokus kepada agihan saiz zarah (PSD), graviti spesifik, had Atterberg dan analisa proktor. Untuk analisa parameter kekuatan ricih, ia ditentukan dan dianalisiskan melalui Ujikaji Mampatan Tak Berkurung (UCT). Secara koheren, kaedah penggantian vibro telah digunakan dalam ujian makmal yang berskala kecil sebagai model ramalan untuk pembinaan kumpulan tiang bata hancur. Reka bentuk tiang dibahagikan kepada tiang penembusan separuh yang terdiri daripada ketinggian 60 mm dan 80 mm, dan tiang penembusan sepenuh dengan ketinggian 100 mm. Berat bata hancur yang digunakan adalah menghampiri 1.07% - 4.56% daripada jumlah jisim spesimennya yang menghasilkan kadar pembaikan kekuatan ricih daripada 11.00% - 18.55%. Penggunaan tiang penembusan sepenuh mempertingkatkan kekuatan ricih tanah liat kaolin ke nilai maximum, 26.20kPa ataupun 18.55% berbanding dengan sampel kawalan yang tidak mempunyai peneguhan, dengan mengurangkan penempatan tanah dan mempromosikan penggunaan bahan lestari dalam pembaikan tanah.

Kata kunci: Pengembangan tanah liat, bata, kekuatan ricih, pembaikan tanah, asas

1.0 INTRODUCTION

As the urbanization process from a forest to a huge city has been taking place at a fast pace around the world, having a good infrastructure system as well as proper accommodation for the residents in the country has been a great concern. The need for land is associated with the transformation of countries especially the developing nation such as Malaysia, which is located in Southeast Asia. Soft clay is abundantly dispersed throughout Malaysia, which constantly causes issues when projects are to be placed on them. Problems like excessive settlement, landslides, and slope failure during excavation are always brought on by soft clay. It can be difficult to choose the ideal location for construction because the area is so rich in soft clay soil. Association of different experts in various fields including engineering, biology, and chemistry has produced innovative solutions for improving the weak soil [1]. The biocementation of organic soil and the engineering of fungal networks are two examples of conventional ground improvement strategies that have also been studied and practiced by numerous researchers recently [2], [3]. Due to its general characteristics, such as high compressibility, insufficient shear strength, and low permeability, this type of soil frequently creates problems. For clay enhancement in construction, sand that is silty or clayey and has a hardness ranging from soft to medium and an undrained shear strength of 0 to 50 kPa [4] is necessary to address these issues with highly compressible and lower shear strength value [5]. Therefore, poor soft clay soil is required to be modified to support massive construction projects like building embankments in Peninsular Malaysia's coastal region [6]. In other words, there will be a demand for the use of soft clay soil for development. Theoretically, for improving the geotechnical properties of soft clay soil, there are four (4) categories of known soil improvement techniques: i.e. mechanical, chemical, hydraulic, and natural alteration can be chosen [7] . Building columns that are composed of coarse aggregates such as stone or sand is one of the methods that is frequently used in the geotechnical field. Since it is widely used, the design of the column has been extensively corrected and changed by numerous researchers utilizing various materials to achieve a better shear strength improvement. The design parameter of the column reinforcement is linked to various materials used in the construction of stone columns. Additionally, it was demonstrated by researchers that the use of waste brick can enhance the properties of expansive soil, particularly when building foundations and embankments [8], and that the addition of a small quantity of recycled crushed brick can enhance the properties of dry and temperature shrinkage of cement stabilized recycled mixture [9]. Coherant to that, the usage of optimum amount of crushed brick in earthwork can increase the flexural strength of stabilized earth block [10], it may be applied as a replaced aggregate in the soil stabilization application of flexible and rigid pavement [11].

In the 21st century, the concept of sustainability has been raised to bring into the construction industry due to the environmental challenges, especially the global warming issue. The buildings will approximately use 40% of the world's raw materials and emit 30% of the carbon dioxide that is released into the atmosphere [12]. While in Malaysia, based on the 10th and 11th Malaysia Plans between 2011-2015 and 2016-2020, the plans emphasized providing affordable houses to our people from poor to middle-income households by practicing sustainable concepts in development [13], [14]. However, it has been confirmed that many countries that intend to adopt the sustainable concept are facing issues like limited availability, proper code and regulations as well as lack of readily available accessible information. A product, material, or industrial activity is considered waste from construction if it has no residual value [15]. Brick, which is the primary building material used in building a firm structure, has been identified as one of the highest wastes generated throughout the construction process [16]. Besides, research evidence has presented the collection of demolished brick mansory waste from the construction activity was reused in civil engineering application for instance the preparation of cement stabilized adobe block [17]. Regarding the problem, replacing stone columns with coarse type material or recycled debris such as crushed brick in the granular column construction can lessen their detrimental effects on the environment at the same time contributing to advanced knowledge.

2.0 EXPERIMENTAL INVESTIGATION

The materials used in the study which included kaolin clay and crushed brick were discussed in the following sub-section. The experimental methods were also discussed on how the works were carried out.

2.1 Materials

In the first approach of this study had decided choosing kaolin clay S300 and coarse type material, crushed brick as the replacement of coarse aggregate. Kaolin (M) Sdn. Bhd which is located in Selangor, Malaysia provided the kaolin clay S300. The general formula of kaolinite is $Al_2Si_2O_5(OH)_4$ known as aluminum silicate hydroxide which consists of aluminum, silicon, oxygen, and hydroxide elements. By nature, this material is convenient for mixing purposes as it is easily broken when in contact with water, which is a hydrophilic material that easily obtains a slurry product for the preparation process of homogeneous soft clay. From the feature of kaolin clay S300, it is a white powder and fine-grained material. Kaolin clay S300 is commonly referred to as soft clay soil due to its natural behaviour. From the previous study, this material was proved to have higher natural moisture content as shown in Table 1 [18]. Besides, this material is also behaving like silty material which consists of 47% of silt. Similar clay was obtained from English India Clay Limited, Trivandrum and has a liquid limit of 66%, a plastic limit is 33%, and a specific gravity value of 2.70 [19], which shows not much different from kaolin clay S300. Furthermore, other engineering properties such as moisture content and permeability or hydraulic conductivity are also important parameters to be known before using the material. Table 2 shows the MDD, OMC, and permeability values as reported by previous study [18].

Table 1 Properties of kaolin clay [18]

No.	Physical parameters	Value
1	Colour	White
2	Natural water content (%)	1.58
3	Specific gravity	2.59
4	Atterberg limits:	
	• Liquid limit, LL (%)	77.93
	• Plastic limit, PL (%)	39.10
	• Plastic Index, PI (%)	38.83
5	Sieve analysis:	
	• Sand (%)	0
	• Silt (%)	47
	• Clay (%)	53

Table 2 Comparison of results from standard compaction and falling head test

Parameters	Researchers			
	[20]	[21]	[22]	[23]
MDD, γ_{dry} (Mg/m^3)	1.30	1.63	1.78	1.58
OMC, w_{opt} (%)	37.00	18.10	18.37	20.00
Permeability, k (m/s)	4.5 x 10^{-9}	5.80 x 10^{-10}	5.00 x 10^{-7}	1.12 x 10^{-9}

The crushed brick was obtained from Batu Bata Kah Wee Sdn. Bhd. located in Johor, Malaysia. Figure 1 shows the bricks after the burning process. Generally, the brick color varies from light to dark red color which is mainly depending on the amount of mineral present in the brick. In the brick production process, the burning degree which is part of the manufacturing process governs the density of brick, where the increase in brick density to the optimum value of 1.7g/cm^3 and thus will cause an increase in its compressive strength to 20MPa with 0% of wt (waste glass) added [24]. When the density of the brick is changed, the volume of the brick will alter and lead to a change in voids ratio which will affect the compressibility. Figures 2 and 3 show the relationship of bulk density in accordance to the heating temperature, and the compressive strength to the heating temperature [25]. Both figures have proven that the bulk density and compressive strength can be increased if the temperature changes.

Figure 1 Burnt brick from kiln

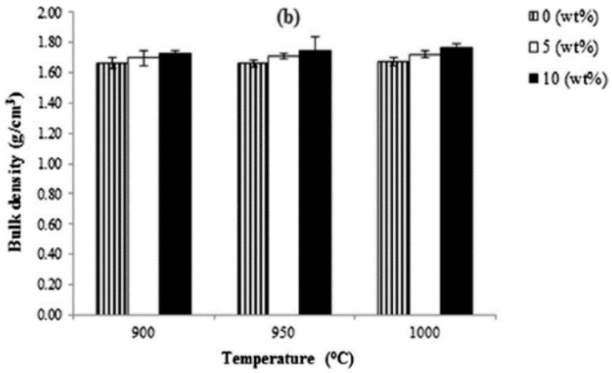


Figure 2 The influence of temperature in accordance to its bulk density [25]

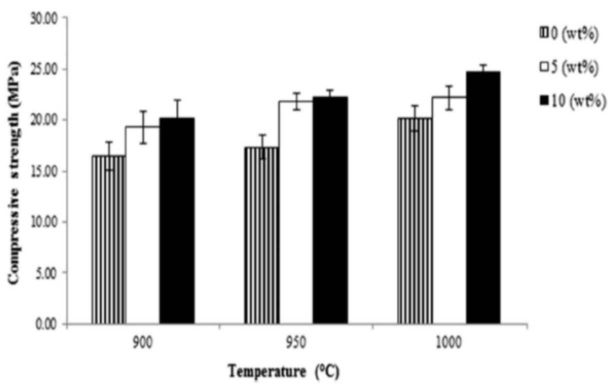


Figure 3 The influence of temperature in accordance to its compressive strength [25]

2.2 Experimental Setup

The engineering properties of crushed brick and kaolin clay S300 were ascertained as the initial phase in this investigation. The physical properties of kaolin clay S300 were determined by hydrometer test, pycnometer test, standard compaction test, falling head test, and Atterberg limit tests. As for crushed brick properties, the related geotechnical tests conducted include mechanical sieve analysis, constant head test, and pycnometer tests. Further analysis was done on the crushed brick columns which were built beneath the kaolin clay for the identification of shear strength by the Unconfined Compression Test (UCT). Table 3 shows the tests being conducted with the relevant standard.

Table 3 Standard of laboratory tests

Experimental Material	Test	Standard
Kaolin Clay S300	Hydrometer	BS 1377: Part 2: 1990: 8.3
	Pycnometer	BS 1377: Part 2: 1990: 9.6
	Standard Compaction	BS 1377: Part 2: 1990: 3.3
	Falling Head	ASTM D 2434
	Atterberg limit	
	Liquid Limit	BS 1377: Part 2: 1990: 4.3
	Plastic Limit	BS 1377: Part 2: 1990: 5.3
Crushed Brick	Mechanical Sieve Analysis	BS 1377: Part 2: 1990: 9.6
	Pycnometer	BS 1377: Part 2: 1990: 8.3
	Constant Head	ASTM D 2434
Soft Clay Reinforced with Group Crushed Brick Columns	Unconfined Compression Test (UCT)	ASTM D 2166

The hydrometer test was conducted based on the relevant standard as tabulated in Table 3. This test is specially designed for the particle size distribution (PSD) of fine particles which passes through the 63 µm sieve, for this study, kaolin clay S300. For coarse type material, mechanical sieve analysis complies with the BS 1377: Part 2: 1990: 9.6 was carried out in 10 minutes for crushed brick material to determine its PSD. The sieve size in this test includes 10 mm, 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm, 0.15 mm, and 0.063 mm. Besides, the Atterberg limit test which comprises the liquid limit test and the plastic limit test was conducted based on the standards as stated in Table 3. The liquid limit test was conducted by cone penetration method and the kaolin used has passed through the 425µm sieve. The test was followed by the plastic limit test, the kaolin was molded into a spherical shape as depicted in Figure 4(a).

Furthermore, the Standard Compaction Test was conducted in accordance with BS 1377: Part 2: 1990: 3.3. as shown in Figure 4(b). About 3.5 kg of oven-dried kaolin clay which passes through the 4.75 mm sieve size was used for the determination of OMC and MDD. Based on Table 3, the pycnometer test was conducted for both materials, kaolin clay and crushed brick. 20g of oven-dried samples were prepared and conducted twice to obtain an accurate value where the test was stopped when the value did not vary more than 0.04 Mg/m^3. For the determination of hydraulic conductivity, a falling head test was conducted for kaolin clay and a constant head test for crushed brick and all of them were based on ASTM D 2434.

In this study, the UCT was conducted based on ASTM D 2166 as shown in Figure 4(c). The crushed brick column preparation used the OMC value determined from the compaction curve based on the standard compaction test. The study used 300g of air-dried kaolin clay to construct control samples or with no crushed brick reinforcement as the reference point for the result analysis for crushed brick columns. The crushed brick columns were made homogeneously by ensuring the same density of columns was produced. Besides, a customized mold was used for the building process of columns. The customized mold was filled with the wet kaolin, compacted into three layers which have 10cm height and 5 cm diameter was used throughout the process. Before pouring the crushed brick, the holes were created at the predetermined diameters of 10 mm and 16 mm by using a drilling bit. To ensure a low amount of air gaps, the crushed brick was compacted using the backside of the drilling bit after it had been poured. Figure 4(d) depicts the constructed crushed brick column.

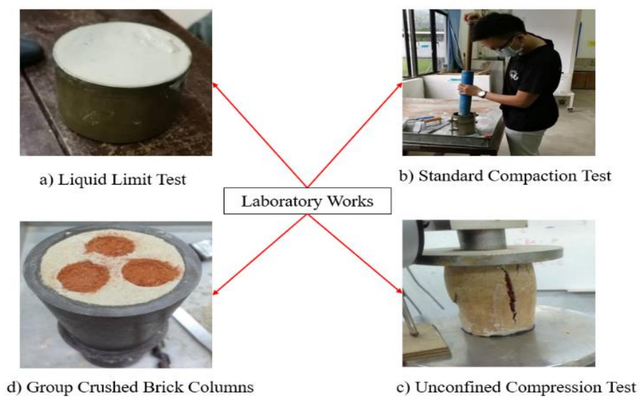


Figure 4 Process of laboratory works (a) Atterberg limit test - liquid limit (b) Standard compaction test (c) Unconfined compression test (d) Construction of group crushed brick columns

The UCT test was conducted by referring to Table 4, which recorded and showed clear details about the volume and density of crushed brick columns. From UCT, the authors recorded the result of shear strength, and by computing the percentage, the shear strength improvement was obtained. Besides, the test was conducted by shearing the specimen at a constant rate of axial deformation. Since there is no confining pressure or equal to zero, the authors stopped the test when failure of the specimen such as bulging is noticed.

2.3 Design of Crushed Brick Column

The crushed brick column was designed after considering several factors such as the D/d ratio and the arrangement of the columns. By referring to the previous study and data of the small-scale laboratory granular column preparation using different types of recycling and disposal materials [26]–[28], the process was executed within the 50 mm diameter of the prepared kaolin clay specimen, the detailed arrangement of the crushed brick columns is depicted in Figure 5. Regarding the D/d ratio, the D is the diameter of the crushed brick column while the d is the diameter of the crushed brick, which has an average value of 1.075 mm as referred to in Table 3. Previous researchers have used the Polypropylene (PP) column which has a D/d ratio of 8.47 and 13.55 and showed shear strength improvement [29]. By calculation, the D/d ratio obtained for both diameters are 9.30 and 14.88 which are similar to the previous values.

Before calculating the column parameters that can affect the overall performance such as the Height Penetration Ratio (H_c/H_s), Height over Diameter of Column Ratio (H_c/D_c), and Volume Replacement Ratio (V_c/V_s) as tabulated in Table 5, the basic dimension of each design was determined and computed as shown in Table 4. From this table, a kaolin specimen with no column reinforcement was classified as a control sample, 60 mm, and 80 mm height columns are classified as partially penetrated columns while 100 mm height was categorized as fully penetrated columns. Regardless of the type of columns, each specimen consists of 3 built columns and they are named according to "G" in front of it signifies that this is a group column, and "1060" means 10 mm diameter with 60 mm height.

Table 4 Mass of crushed brick used with respect to its volume and density

Diameter of group of crushed brick column (mm)	Length of column (mm)	Volume of column (mm^3)	Density of crushed brick (g/mm^3)	Mass of crushed brick (g)
10	60	4712.39	0.00068	3.20
	80	6283.19		4.27
	100	7853.98		5.34
16	60	12063.72	0.00068	8.20
	80	16084.95		10.94
	100	20106.19		13.67

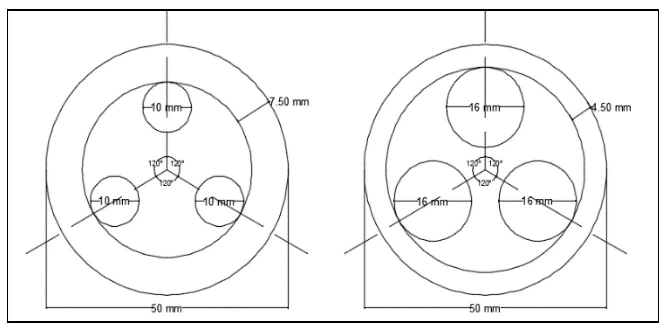


Figure 5 Detailed arrangement of crushed brick columns

Table 5 Crushed brick column parameters

Design	H_c/H_s [a*]	H_c/D_c [b*]	V_c/V_s [c*]
Control	-	-	-
G1060	0.6	6.00	0.0240
G1080	0.8	8.00	0.0320
G10100	1.0	10.00	0.0400
G1660	0.6	3.75	0.0614
G1680	0.8	5.00	0.0819
G16100	1.0	6.25	0.1024

3.0 RESULTS AND DISCUSSION

This section will concentrate on the laboratory data where the properties of materials are analyzed while the shear strength improvement value was used to examine the effectiveness of the crushed brick column functioning as the granular column. Additionally, the method of correlating the parameters of shear strength was described using the proper equations and graphs.

3.1 Kaolin Clay 300 and Crushed Brick Engineering Properties

After conducting all the related geotechnical tests which as referred to in Table 3, the properties are tabulated in Tables 6 and 7.

Table 6 Kaolin clay S300 properties

Experimental Material	Test	Parameter	Result
Kaolin Clay	Hydrometer Test	USCS	ML
		AASTHO	A-6
	Standard Compaction	Max. Dry Density	1.59 Mg/m^3
		Optimum Moisture Content	20.50%
	Pycnometer Test	Specific Gravity, G_s	2.63
	Falling Head Test	Permeability	6.05 x 10^{-12} m/s
	Atterberg Limit	Liquid Limit, LL	38.00%
		Plastic Limit, PL	32.00%
		Plasticity Index, PI	6.00%

Table 7 Crushed brick properties

Experimental Material	Test	Parameter	Result
Crushed Brick	Sieve Analysis	AASTHO	A-1-b
		Particle Size	0.15 – 2 mm
	Pycnometer Test	Specific Gravity, G_s	2.59
	Constant Head Test	Permeability	1.30 x 10^{-3} m/s

From Tables 6 and 7, kaolin clay was generally classified as low plasticity soil while crushed brick behaves like fine sand to gravel material. Regarding the particle size distribution of both materials, they are shown in Figures 6 and 7. From Figure 6, the kaolin clay was determined as poorly graded and its particle size was mainly ranging between 5μm to 8μm. For crushed brick, the graph depicted in Figure 7 shows that it was a well-graded material. From the standard compaction curve, as shown in Figure 8, the optimum moisture content obtained was approximately 20.50% with a maximum dry density of 1.59 Mg/m^3. Kaolin clay S300 was a low permeable soil while crushed brick was a high permeable soil with 6.05 x 10-12 m/s and 1.30 x 10-3 m/s, respectively.

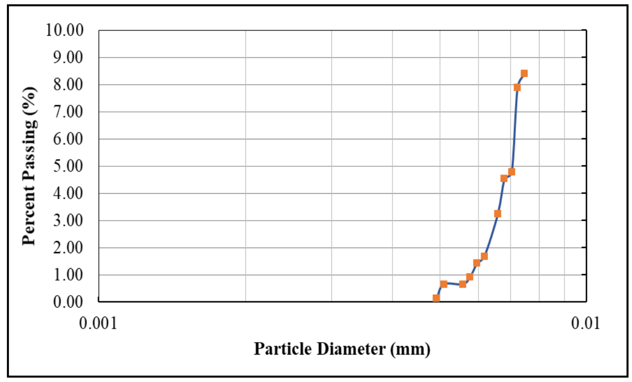


Figure 6 Particle size of distribution of kaolin S300

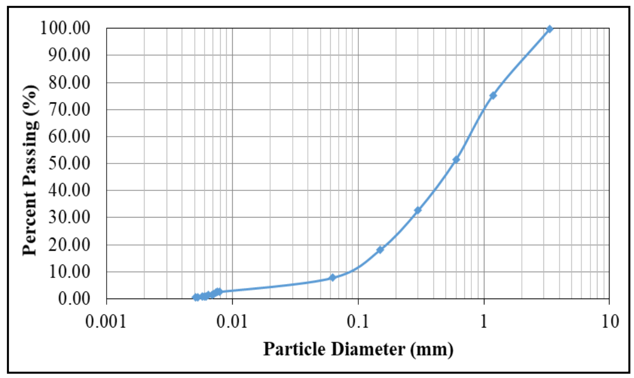


Figure 7 Particle size of distribution of crushed brick

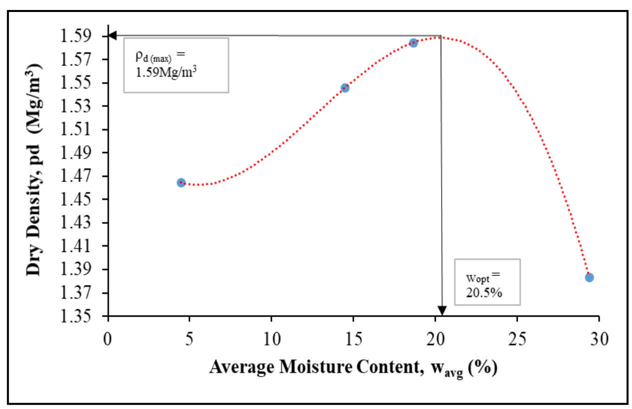


Figure 8 Compaction curve of kaolin S300

3.2 Shear Strength Analysis Towards the Installation of Crushed Brick Columns

The results of the UCT laboratory work for shear strength, S_u, and shear strength improvement, ΔS_u, were summarized in Table 8 and represent the shear strength parameters. Three (3) specimens were examined for each parameter, including the control sample and the average shear strength value was used to obtain the final shear strength value. According to the table, shear strength improvement for the 10 mm column diameter was inconsistent, but shear strength improvement for the 16 mm column diameter was showing an increasing trend.

Apart from that, the results from the UCT were analyzed in terms of stress-strain behavior was tabulated in Table 9. It was noticed that the maximum deviator stress occurs when the G16100 column was tested, and recorded 52.41kPa as compared to the control specimen with only 44.19kPa or 18.60% improvement. Although a previous study proved that the disturbance of the original state of the soil may cause a reduction in its shear strength and the maximum deviator stress, q_u [30], the current study shows that the optimum amount of replacement occurs at the maximum size of the column. The maximum deviator stress value shows a similar result of improvement for 10 mm diameter columns, Δq_u ranging between 11.04% – 14.82% and this trend is observed to be the same trend for partially penetrated 16 mm diameter columns. For the axial strain value, the largest value occurs when G10100 was tested but the maximum deviator stress is not the highest value. Figure 9 shows the relationship between the deviator stress and the axial strain value obtained from UCT. The values signify that the maximum deviator stress did not occur in correspond to the maximum value of axial strain. The highest axial strain recorded was approximately 3.70% at the G1060 and G10100 design, where the crushed brick replacement amount was lesser as compared to the 16 mm diameter of crushed brick columns. This can be considered as the less disturbance of the soil during the excavation process as proposed by [31], leading to a higher value of axial strain when the specimen was being sheared under the UCT.

Table 8 Results obtained from UCT

Design	H_c/H_s	H_c/D_c	V_c/V_s	S_u (kPa)	ΔS_u (%)
Control	-	-	-	22.10	
G1060	0.6	6.00	0.0240	24.82	12.31
G1080	0.8	8.00	0.0320	24.53	11.00
G10100	1.0	10.00	0.0400	25.37	14.80
G1660	0.6	3.75	0.0614	24.98	13.03
G1680	0.8	5.00	0.0819	25.47	15.25
G16100	1.0	6.25	0.1024	26.20	18.55

Table 9 Stress-strain behavior under axial load

Design	Maximum Deviator Stress, q_u	Maximum Deviator Stress Improvement, Δq_u	Axial Strain, ε (%)
Control	44.19	-	2.34
G1060	49.63	12.31	3.70
G1080	49.07	11.04	3.58
G10100	50.74	14.82	3.75
G1660	49.96	13.06	2.35
G1680	50.94	15.27	3.01
G16100	52.41	18.60	2.51

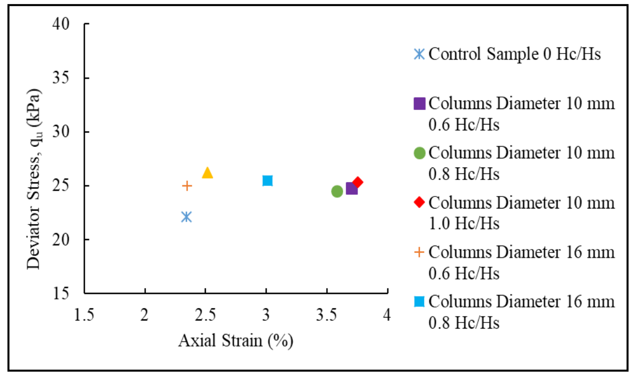


Figure 9 Deviator stress versus axial strain under UCT

3.3 Correlation of Shear Strength Improvement with Height Penetration Ratio

The best value of shear strength enhancement is reported with a 1.0 height penetration ratio, according to the UCT result presented in Table 8. The highest improvement was observed in a fully penetrated column with a diameter of 16 mm, while the least improvement was observed in a partially penetrated column with a diameter of 10 mm and a height of 80 mm, which was due to the ineffective of the unreinforced bottom part of the specimen during the load transference process, resulting in the earlier failure of the specimen. The highest improvement occurred with the critical height of 1.0 was proven by the function of crushed brick being a coarse-type material, which was able to transfer the axial loading throughout the entire reinforced part effectively to the bottom of the specimen. According to Table 8, the shear strength improvement for the crushed brick column with a 10 mm diameter and height penetration ratios of 0.6 and 1.0 is 12.31% and 14.80%, respectively. On the other hand, the same height penetrating ratio of 0.6 led to an improvement of 13.03%, and a height penetration ratio of 0.8 led to an improvement of 15.25%. Referring to Figure 10., the correlation between this shear strength parameter was determined through equation (1) where the $R^2 = 0.9877$ and $R^2 = 0.9163$ for equation (2) using the control sample as a reference point, expressing the relationship between a set of dependent and independent variable by statistical approach [32].

$$\Delta Su = 14.496(H_c/H_s) + 0.8274 \quad (1)$$
$$\Delta Su = 18.697(H_c/H_s) + 0.4897 \quad (2)$$

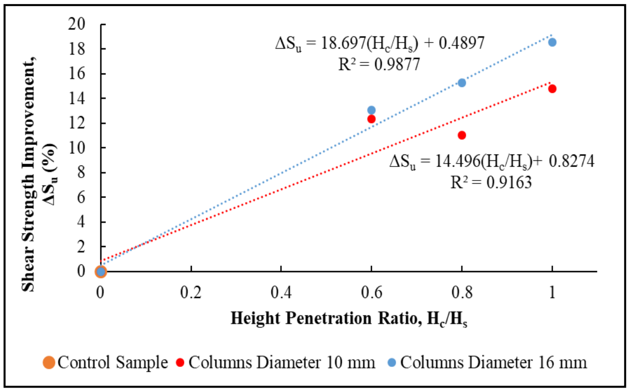


Figure 10 The correlation graph between shear strength improvement and height penetration ratio

3.4 Correlation of Shear Strength Improvement with Height Over Diameter of Column Ratio

Using Figure 11 as a reference, it was noted that the shear strength improvement was the greatest for the H_c/D_c value of 6.25, while the smallest improvement was observed at 3.75. According to previous studies, the ideal range for H_c/D_c is between 4 and 6 times [33]. The regression value, R^2 = 0.9163 was shown in equation (3) for the 10 mm diameter of crushed brick columns while R^2 = 0.9877 was for the 16 mm diameter of crushed brick column as presented in equation (4) by using the control sample as a reference point.

$$\Delta Su = 1.4496(H_c/D_c) + 0.8247 \quad (3)$$
$$\Delta Su = 2.9916(H_c/D_c) + 0.4897 \quad (4)$$

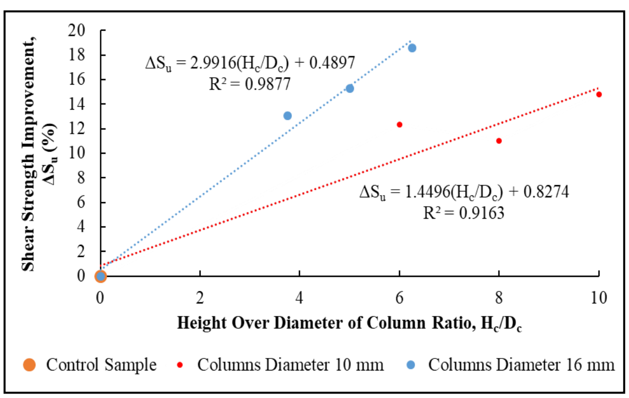


Figure 11 The correlation graph between shear strength improvement and height over diameter of column ratio

3.5 Correlation of Shear Strength Improvement with Volume Replacement Ratio

The highest value of V_c/V_s of 0.1024 indicates an increase of 18.55%, while the lowest value of V_c/V_s of 0.0240 shows an improvement of 12.31%, which was not the least value of improvement. This ratio indicates that the column's volume and the increase in shear strength are related. Figure 12 displays the regression equations (5) and (6) for column diameters of 10 mm and 16 mm, respectively, with R^2 values of 0.9163 and 0.9877 by using the control sample as a reference point.

$$\Delta Su = 38.451(V_c/V_s) + 0.8274 \quad (5)$$
$$\Delta Su = 19.374(V_c/V_s) + 0.4897 \quad (6)$$

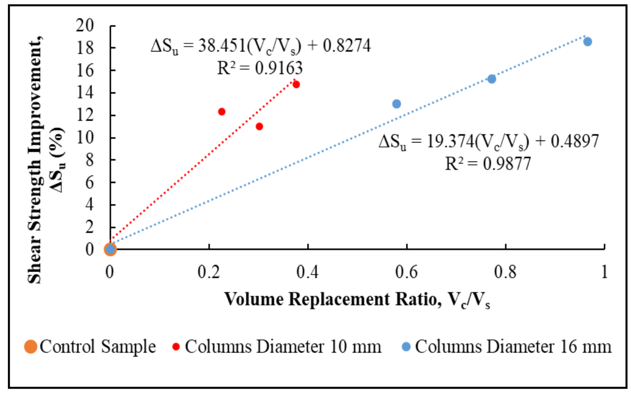


Figure 12 The correlation graph between shear strength improvement and volume replacement ratio

4.0 CONCLUSION

Based on the current research using crushed brick as a replacement for coarse aggregate reinforcement in soft kaolin clay by the technique of granular column installation, several conclusions can be drawn based on the laboratory results and data obtained.

The kaolin clay is naturally soft and has high compressibility while crushed brick like sand and gravel type material based on their engineering properties, which was presented by a previous study the brick is capable of substituting the naturally excavated soil [17]. Hence, the combination of both materials can mediate the failure risk of the structure as it reduces the excessive pore water pressure within itself by providing a good drainage system.

After the crushed brick columns were installed beneath the kaolin clay, it was discovered that the biggest shear strength improvement of 18.55% was produced by a 16 mm column with a H_c/H_s ratio or a critical length of 1.0, followed by 15.25% which was under the same category but with H_c/H_s ratio of 0.8. Besides, a longer column length signifies the larger portion of crushed brick being replaced in the specimen and hence, it can withstand a higher value of axial loading. Regarding the H_c/D_c ratio, the value of 6.25 gave the highest improvement, whereas the value of 8.00 caused the least improvement. The volume replacement ratio, V_c/V_s indicates that the ratio of 0.1024 produced the highest shear strength value while 0.032 gives the least shear strength improvement. Generally, the samples will be much stronger when the volume of replacement is higher for each diameter of the column.

The shear strength improvement results were analyzed through the correlation technique, which simplified the complex variables in the simpler linear equations [32]. From Figures 10, 11, and 12, the correlated results were accurate where all the regression equations possessed R^2 value of more than 0.9.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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