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The shear strength of soft clay reinforced with single and group crushed brick column

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Abstract. Soft Clay is often known to be a problematic soils in construction because of its low strength and high compressibility characteristic. Before construction begins, ground improvement needs to be done to improve the soil bearing capacity so that the superstructure can be placed on top of it and reduce settlement and consolidation. In this study, the soft clay is going to be reinforced with crushed brick column which is part of construction waste produced during construction stage to achieve sustainable construction. This study was aimed to investigate the effectiveness of single and group crushed brick column in improving the shear strength by using laboratory scale model. Kaolin is being used as soil sample while crushed brick as the reinforced column. Few laboratory tests are conducted to determine the properties of kaolin clay and crushed brick. Unconfined Compression Test (UCT) also used to test the shear strength of the reinforced kaolin samples The improvement of shear strength of single crushed brick column with area replacement ratio of 4.00% (10mm column diameter) are 3.34%, 4.60% and 1.07% at sample penetration ratio, Hc/Hs of 0.6, 0.8 and 1.0 respectively while for area replacement of 10.24% (16 mm column diameter) are 7.56%, %, 16.37% and 4.97% at the same penetration ratio.. The result shows that the improvement shear strength for height penetration ratio of 1.0 is 13.33% which was the highest, while 0.6 and 0.8 are 12.31% and 9.79% respectively for group crushed brick columns with diameter 10mm. The improvement of shear strength is highest for height penetration ratio of 1.0 with 16.10% improvement which was slightly higher than 0.6 and 0.8 which were 13.49% and 11.35% respectively in sample reinforced with grouped columns with diameter 16mm. It can be concluded that the shear strength of soft clay could be improved by installation of single and group crushed brick column.

1. Introduction

Malaysia has undergone over 60 years of rapid industrialization. However, most of the development projects have been unsustainable and it is crucial that sustainable approaches to be taken in new development projects. According to the World Green Building Council, buildings in all part of the world account for 30% of carbon dioxide emissions, and 40% of raw materials used 40% of the world's energy consumption [1]. Over a building's lifecycle, including planning, construction and building usage and maintenance, a number environmental problems are created. These include loss of agricultural land, deforestation and pollution. The rapid development of Malaysia has brought up the blooming of construction sector. Building infrastructures, as well as new housing estate will increase the demand of construction materials to another new high. With more and more development projects being started in Malaysia, the construction waste produced will be increased tremendously, and thus creating impacts to the environment, and these wastes has been causing environmental problems such as land settlement as well as ground water pollution, and it will be incurring high extra construction cost due to its managing fee. Brick as one of the most common construction materials will also be contributing to the rising amount of waste. Therefore, the unavoidable generated waste should be turned to an economical effective product, which can help in generating new income for a project, at the same time reduce its destructive impact to the environment [2].

Soft clay always creates problem such as excessive settlement, landslide and causing slope failure during excavation. Problematic soft clay also causes landslide which will lead to severe damage to existing structures and even depletion of life [3]. In order to solve this problem, the mechanical properties of soft soil has to be engineered so that proper treatment can be done accordingly base on this problem. In order to solve both problems, it comes with an idea of stabilizing the problematic soft clay, using the brick waste generated in construction activities. The engineering properties of soft clay could be monitored and improved by using the brick particles. Crushed brick particles forming columns are designed to increase the permeability of soft clay, which can help in accelerating the consolidation process and decrease the compressibility of soil. Therefore, reduction in liquefaction of soil could be able to increase the shear strength and bearing capacity of soil, making it more suitable for construction activities. In this study, the experiments is conducted in small scale laboratory test basis. Unconfined Compression Test, is conducted with “S300” kaolin representing soft clay, embedded with crushed brick particles forming columns. The purpose of study is to determine the shear strength of single and group crushed brick column.

According to [4], in a number of past studies, soil improvement with reinforcing sand columns of different lengths were used to investigate the effect of the column penetration on the improvement of load-carrying capacity of the specimens. Many of the researchers have come up with the ‘critical column length’ idea where the column beyond this length will not improve the capacity of the clay. The value for ‘critical column length’ as proposed by [5] occurred between 4 and 8 times the diameter of the column. For comparison, data by [6] was plotted on the same figure. As proposed by past researchers, “the critical column length” which is between 4 to 8 times the diameters of the column. The hypothesis of a critical column length beyond which the increase in undrained shear strength becomes relatively negligible is in harmony with the result. The cumulative findings may suggest that the height penetrating ratio might play more significant role in improving the undrained shear strength of the clay soil compared to the height over diameter of the column ratio.

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2. Materials and methods

Kaolin grade S300 from Kaolin Malaysia Sdn. Bhd., Selangor is selected in this research in order to represent the clay in natural condition. The mechanical properties of kaolin with weak bearing capacity and high compressibility, with a consistent and soft texture allows it to produce homogenous soft clay samples. The kaolin sample is also easily available with reasonable price. For the columns used to reinforce the soft clay sample, clay brick is used as its material. Common clay brick from Batu Bata Kah Wee Sdn. Bhd. which is located in Batu Pahat is used in this research as the column material. Using of clay brick in the research allows the industry to identify potential waste materials, especially from the construction wastes to replace the usage of natural resources such as sand or rocks in soil improvement activities. This can reduce the rate of depletion of natural resources as well as damaging the ecosystem. This will also help in reducing the cost in construction activities dependency the non-renewable natural materials

The study of crush brick column has been divided into two categories, single and group. Each categories has 21 samples. Total up to 42 samples were tested to achieve the main objective of the research on how shear strength of soft clay can be optimize. Figure 1 and 2 have shown the setup of the sample prior of shear strength test.

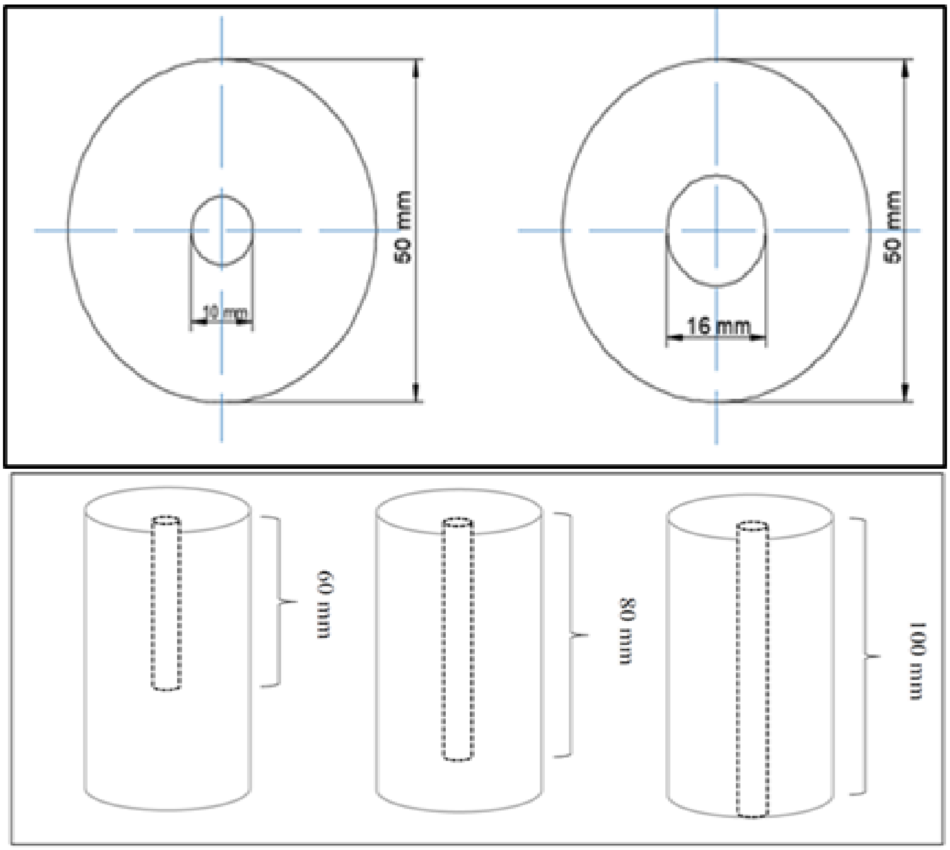

Figure 1. Setup of single crush brick column with distinctive height (60mm, 80mm and 100mm) and column (10mm and 16mm) on S300 Kaolin.

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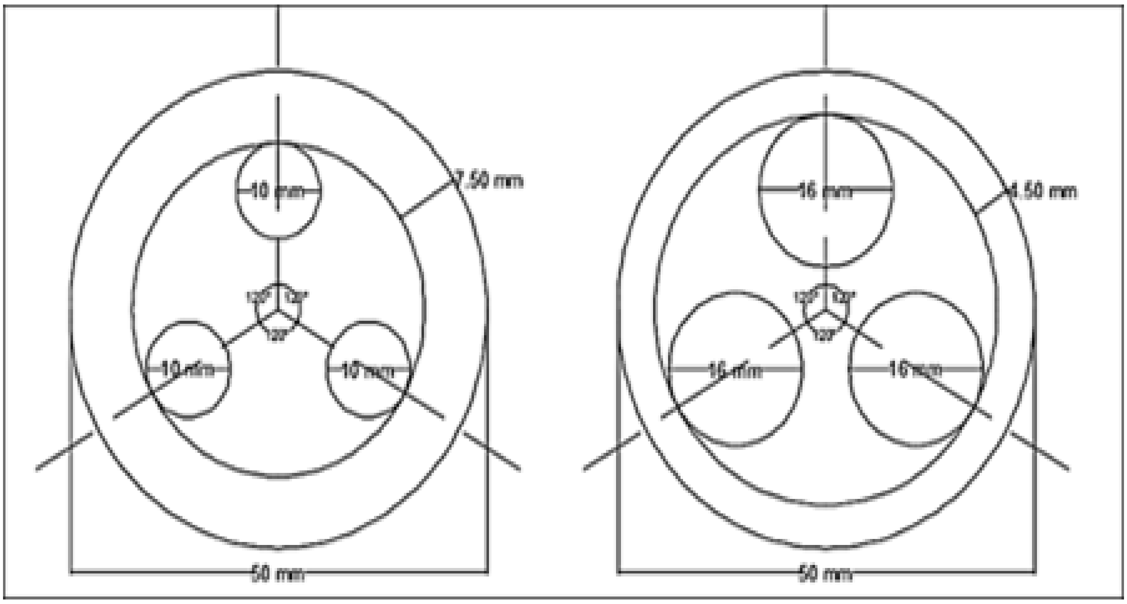

Figure 2. Setup of group crush brick column with distinctive height (60mm, 80mm and 100mm) and column (10mm and 16mm) on S300 Kaolin.

Small scale modelling samples with 50mm in diameter and 100mm in height are prepared by using kaolin as the soft clay and crushed brick as columns material. The standard referred for experimental tests are British Standard (BS) and the American Society of Testing Material (ASTM). The choice of testing methods are subjected to the suitability and availability of the equipment in the laboratory for the respective tests. Each layer was compacted with 5 free fall blows by customized steel extruder. The holes for the installation of crushed brick column were drilled using drill bit of required diameter with the specimens still inside the mould to prevent it from expanding. The sample are formed in 3 batches, so that parameter study were accurate. One specimen was used as ‘control specimen’ where there was no crushed brick column installed in the specimen while the other 6 were installed with 10mm and 16mm column at penetration ratio of Hc/Hs of 0.6, 0.8 and 1.0 respectively as shown in Fig 1 and 2. As for group crushed brick columns, the holes for the columns were drilled with drill bits of 10mm and 16mm diameter for the respective depths.

3. Result and discussion

This study are mainly aim on how crush brick use as shear strength improvement on soft clay, S300. Acknowledge that variable such as diameter and height are playing important role on how can we decide which is the optimum measurement to give highest shear strength improvement. Therefore, this paper divvied the result and discussion into three section which are height penetration ratio, height over column ratio and volume replacement ratio. Table 1 and 2 shows the summary of the shear strength improvement data on 42 samples that been tested using Unconfined Compression Test (UCT).

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Table 1. Results of improvement of shear strength on Single Crush Brick Column.

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	15.49	15.08	17.07	15.88	-
Single Crushed Brick Column (10mm)					
0.6	15.49	18.27	15.48	16.41	3.34
0.8	16.38	15.18	18.26	16.61	4.60
1.0	14.99	15.68	17.48	16.05	1.07
Single Crushed Brick Column (16mm)					
0.6	17.68	15.68	15.54	17.88	7.56
0.8	17.87	17.09	20.45	18.48	16.37
1.0	17.47	17.47	15.08	16.67	4.97

Table 2. Results of improvement of shear strength on Group Crush Brick Column.

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	23.83	20.64	21.82	22.1	-
Group Crushed Brick Columns (10mm)					
0.6	26.42	24.62	23.41	24.82	12.31
0.8	25.46	24.48	23.66	24.53	11.00
1.0	26.62	25.28	24.21	25.37	14.80
Group Crushed Brick Columns (16mm)					
0.6	29.18	22.87	22.89	24.98	13.03
0.8	24.44	23.76	28.20	25.47	15.25
1.0	29.38	26.57	22.67	26.20	18.55

Generally, the shear strength of soil sample would increase with area replacement ratio. Nonetheless, the improvement of shear strength depends also on the other factors, such as penetration ratio, and volume replacement ratio of the crushed brick columns. Therefore, the increment of area replacement ratio might not show increase in shear strength.

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3.1. Height penetration ratio

Figure 3 (left) shows the graph of improvement of shear strength versus height penetration ratio Hc/Hs for single crush brick column. From the graph, it shows that the shear strength was increased by 16.37%, when height penetration ratio was 0.8 for column diameter of 16mm. For height penetration ratio of 0.6 and 1.0, the increment were 7.56% and 4.97% respectively. Meanwhile for column diameter of 10mm, the increase of shear strength were way lower compared to 16mm column. The highest improvement achieved was 4.6% at the height penetration ratio of 0.8. The shear strength for height penetration ratio of 0.6 and 1.0 were increased to 3.34% and 1.07% respectively.

Besides that, from the graph in figure 3 (right), it is shown that the highest shear strength is achieved with most significant improvement when the penetration ratio is 1.0. This happens in both cases with 10mm and 16mm column diameter. This is due to when the both ends of columns are subjected to load, the columns can carry the load without transferring it to the clay. For group crushed brick columns with diameter 10mm, the result shows that the improvement shear strength for height penetration ratio of 1.0 is 14.80% which was the highest, while 0.6 and 0.8 are 12.31% and 11.00% respectively. In sample reinforced with grouped columns with diameter 16mm, the result shows that the improvement of shear strength is highest for height penetration ratio of 1.0 with 18.55% improvement which was slightly higher than 0.6 and 0.8 which were 13.03% and 15.25% respectively. These results were supported by the previous work of [7], [8] and [9] who reported that the result on the encased of sand column does improved the undrained shear strength. The trend can be concluded as accurate as the value of correlation of the trend, R2 are 0.9163 and 0.9877 respectively for both column diameter.

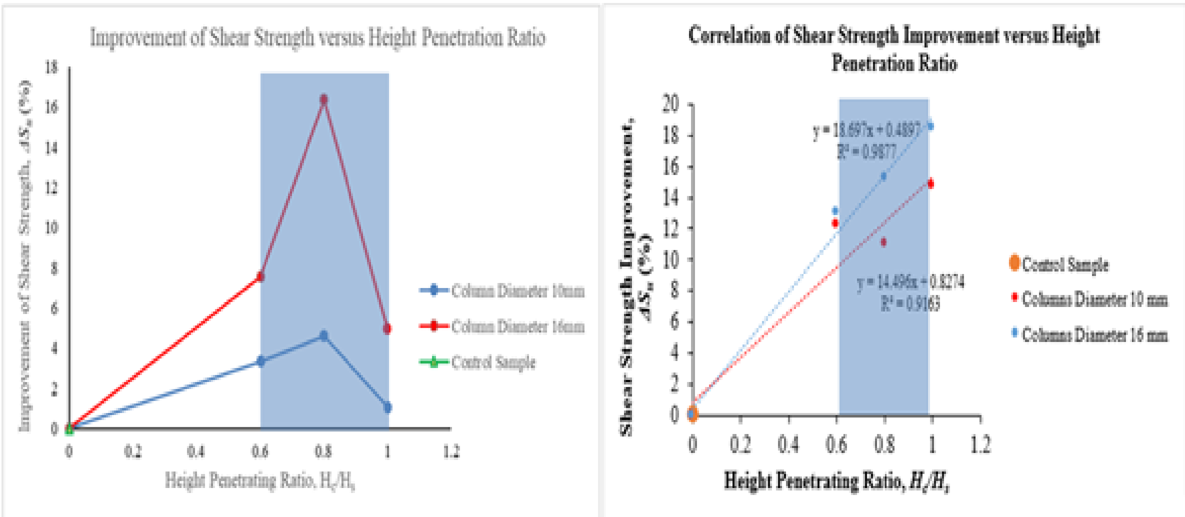

Figure 3. Correlation of shear strength improvement versus height penetration ratio for Single Crush Brick Column (left) and Group Crush Brick Column (right).

3.2. Height over column ratio

Figure 4 (left) shows the improvement of shear strength against height over diameter of column ratio (Hc/Dc) for single crush brick column. According to Maakuroun et al. (2010), the "critical column length" occurred in range 4 to 8 times the diameter of the column (Dc) while [10] stated that "critical column length" lies in the range 5 to 8 times the diameter of the column (Dc). From figure 4 (left), it can be seen that the highest shear strength and greatest improvement achieved when the height over diameter of column is 5, which in line with statement by previous researchers. The shear strength improvement decreased outside the range of critical column length.

However, for group crush brick column, based on [4] there are several past studies for example those by [5] recorded that the most critical column length happened when the ratio of length to diameter is within 4 to 8 times. It is marked in the below graphs for the range of this ratio. In this research, the most critical height to diameter ratio falls in the range is 6. For the result in 10mm columns, it is recorded that the maximum shear strength of clay occurs when the ratio is at 1.0. This result could be due to the higher dependency of the shear strength on the column height in this columns. Figure 4 (right) shows the shear strength improvement versus ratio of column height over diameter.

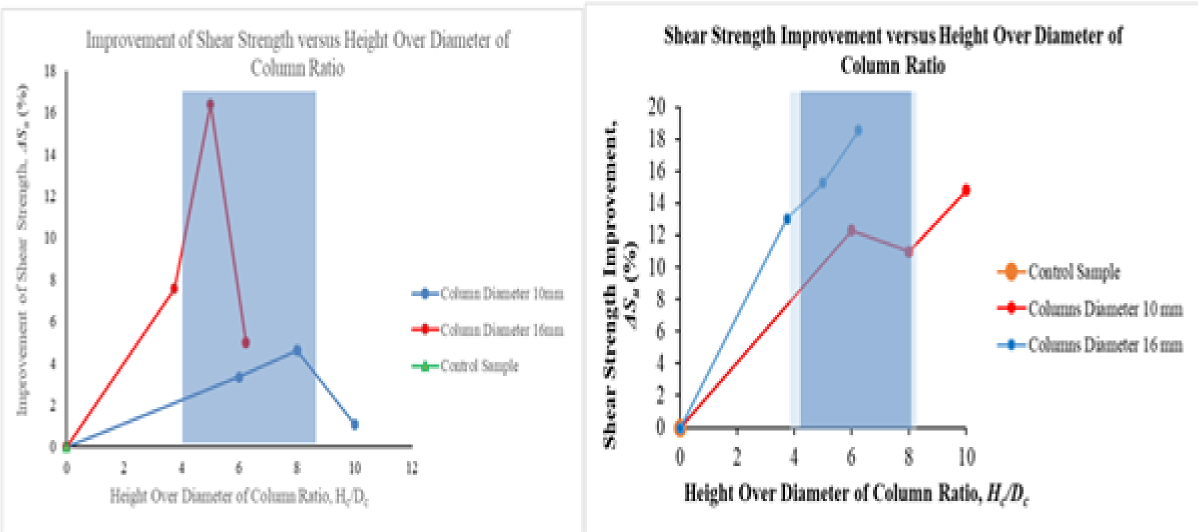

Figure 4. Correlation of shear strength improvement versus height over column ratio for Single Crush Brick Column (left) and Group Crush Brick Column (right).

3.3 Volume replacement ratio

Generally the strength increase as the volume replacement ratio increase. However, for single crush brick column the improvement shear strength seemed to be more apparent for up to 0.082 replacement when it shows an increase of ΔSu with Vc/Vs. Thereafter, ΔSu decrease with the increased of Vc/Vs. This shows that the improvement in shear strength is not in line with the increase of volume replacement ratio. Figure 5 (left) shows the graph of improvement of shear strength against volume replacement ratio.

Whereas, in volume replacement ratio for group crush brick, the results also show that the improvement is in line with the increase of volume replacement ratio (Vc /Vs). In the graph of shear strength against volume replacement ratio, the shear strength is recorded highest for diameter 10mm at volume replacement ratio of approximately 0.38 and that is 0.97 for 16mm diameter. Figure 5 shows the shear strength versus column volume penetration ratio. The graph of shear strength improvement versus volume replacement ratio is shown in figure 5 (right).

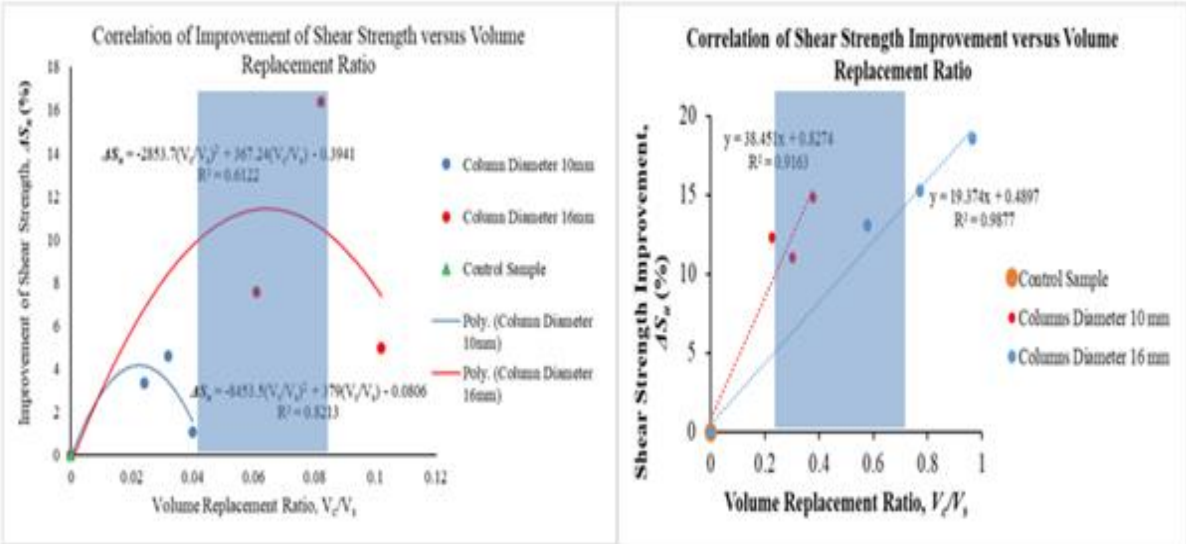

Figure 5. Correlation of shear strength improvement versus volume replacement ratio for Single Crush Brick Column (left) and Group Crush Brick Column (right).

4. Conclusion

The focus of attention of this study is to find out whether there is any improvement on undrained shear strength of soft kaolin soil after reinforced with single and group crushed brick column with two different column diameters and different length of penetration. Based on result obtained, the following conclusions can be drawn:

- The installation of single crushed brick column has improved shear strength of kaolin clay. It shows that the installation of single 10 mm diameter crushed brick column with penetration ratio Hc/Hs of 0.6, 0.8 and 1.0 has increase the shear strength of kaolin clay.

- Critical column length for single crush brick analysis occurred between 4 to 8 times of the diameter of the column installed based on results from previous researchers. For both 10mm and 16mm column diameter, the highest shear strength obtained at Hc/Dc of 5 which prove that the result is in line with result from previous research works.

- The volume replacement ratio Vc/ Vs shows that for 10mm diameter columns, the maximum shear strength occurs when the ratio is around 0.4 meanwhile the ratio is around 1 for 16mm diameter column.

Acknowledgements
The focus of attention of this study is to find out whether there is any improvement on undrained shear strength of soft kaolin soil after reinforced with single and group crushed brick column with two different column diameters and different length of penetration. Based on result obtained, the following conclusions can be drawn:

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