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Sustainable ground improvement method using encapsulated polypropylene (PP) column reinforcement

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Abstract. This study investigates the effectiveness of encapsulated polypropylene (PP) column in enhancing the undrained shear strength of kaolin (soft clay). The usage of PP in treating problematic soil is a more sustainable and cost-effective alternative compared to other materials. The installation of granular column can be done by using vibro-replacement method. Several geotechnical tests to determine the properties of materials were conducted. The shear strength of treated kaolin sample was examined by using Unconfined Compression Test (UCT). There are seven (7) batches of soil sample in total which included a control sample, three (3) batches of 14 mm and three (3) batches of 20 mm diameter PP column. Different diameters of PP column were examined with 60 mm, 80 mm and 100 mm height, respectively with soil sample of 50 mm in diameter and 100 mm in height. The shear strength improvement of kaolin is 33.82%, 46.51%, and 49.88% when implanted with a PP column with a 7.84 area replacement ratio and 0.6, 0.8 and 1.0 penetration ratio. The soft soil treated using 16.00 area replacement ratio with 0.6, 0.8 and 1.0 penetration ratio has a shear strength increment of 25.22%, 33.39% and 37.59% respectively. In short, the shear strength improvement of the kaolin clay depends on the parameter of the PP column used to reinforce the sample.

Keywords: cost-effective alternative, encapsulated polypropylene column, geotechnical

1. Introduction

Initiation of a construction project is normally challenging if the soil on site is soft and unstable. Soft soil is normally having low shear strength, high compressibility, and low permeability [1]. Moreover, soil with very fine particles like kaolin clay will experience a massive change of soil volume under different conditions [2], leading to uneven settlement and causing severe structural damage to the foundation of a structure [3]. However, soft soil areas are needed to cope with the massive construction development because there is much soft soil at the coastal of Peninsular Malaysia [4]. The usage of soft soil for construction is inevitable for the future generation.

Table 1. Kaolin Clay Properties

Material	Test	Parameter	Result
Kaolin Clay	Soil Classification	USCS	CL
		ASSTHO	A-6
	Standard Compaction	Max. Dry Density	1.60 Mg/m^3
		Optimum Moisture Content	19.00%
	Specific Gravity Test	Specific Gravity, Gs	2.60
	Falling Head Test	Permeability	2.27×10^{-12} m/s
	Atterberg Limit	Liquid Limit, LL	34.41%
		Plastic Limit, PL	23.12%
		Plasticity Index, PI	11.29%

Table 2. Plastic Polypropylene (PP) Properties

Material	Test	Parameter	Result
Plastic PP	Dry Sieve Analysis	USCS	1.18 – 3.35 mm
	Relative Density	Maximum Dry Density	0.75 g/cm^3
		Minimum Dry Density	0.56 g/cm^3
	Constant Head Test	Permeability	5.87×10^{-4} m/s
	Parameter obtained from: Titan Petchem (M) Sdn. Bhd.	Density	0.9 g/cm^3
		Tensile Strength at Yield	330 kg/cm^3
		Elongation at Yield	12.00%
		Flexural Modulus	13 000 kg/cm^3
		Shrinkage	1.30 – 1.40%
		Water Absorption	0.002%
		Melt Flow Rate at 230ºC	20 g/10 min

Table 3. Geotextile MTS130 Properties

Material	Test	Parameter	Result
Geotextile MTS130	Parameter obtained from: Titan Petchem (M) Sdn. Bhd.	Material	Polyester
		Unit Weight	130 g/m^3
		Thickness	1.08 mm
		Max. Tensile Strength, MD	10.0 kN/m
		Max. Tensile Strength, CD	9.3 kN/m
		Elongation at MD	56.00%
		Elongation at CD	64.00%
		CBR Puncture Strength	2.2 kN/m
		Trapezoid Tearing Strength, MD	350 N
		Trapezoid Tearing Strength, CD	280 N
		Index Puncture Strength, MD	310.3 N
		Apparent Opening Size	140 µm
		Vertical Permeability	0.27 cm/s

There are different types of soil improvement methods to treat different conditions of soft soil. Installation of stone columns as soil improvement is gaining popularity in this era because of its reasonable cost and ability to treat different problematic soil types [4-5]. Stone columns can effectively reduce water table and mitigate the massive change in soil volume, making the soil more sustainable to soil settlement.

Other worldwide issues that caught social attention are abundant plastic pollution. Because of its lightweight, stability, durability, and cost, the amount of plastic grew rapidly after its publication. More than 5.25 trillion particles weigh 268940 tons of floating plastic on the surface of our ocean [6]. Amidst the recycled products, there is granular plastic that can replace stone columns in geotechnical soil improvement. The usage of PP as a granular column can effectively cut down the amount of plastic in landfills. Geosynthetic can solve the problem of column bulging by enhancing the stiffness of the column [7]. In this study, MTS130 is used as a geotextile in order to encapsulated the PP column.

2. Materials and Method

In this study, kaolin clay is used as the problematic and soft soil, while encapsulated PP column with MT130 non-woven geotextile was used as the reinforced granular column. Tests were carried out to identify the properties of each material used. Since the PP is not good at absorbing water, there are many properties of PP that cannot be obtained from the tests in a geotechnical laboratory. Therefore, some of the granular PP's properties were obtained from the Titan Petchem (M) Sdn supplier. Bhd. The properties of all materials are shown in Table 1 to Table 3 below.

In order to standardize all the samples tested, the parameter that is fixed in this experiment is the density of the sample. Since the volume of the mould is fixed, so the weight of the sample was set to be constant over the testing. The fixed mass of kaolin with optimum moisture content was compacted into 50mm diameter and 100 mm height specimens. A hole is drilled using the drill bit at the centre of the soil sample, as shown in Figure 1.

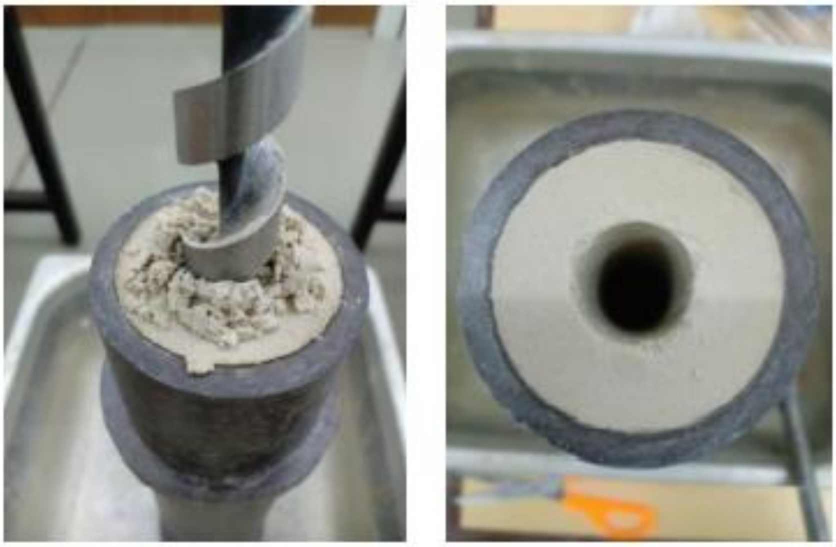

Figure 1. PP Column Installation Drilling Hole

The geotextile was installed, followed by granular PP. The dimension of the PP column used in this study is clearly shown in Table 4.

Table 4. Dimensions of PP Column.

Sample	D_c (mm)[a*]	V_c/V_s[b*]	H_c (mm)[c*]	H_c/H_s[d*]	H_c/D_c[e*]
GIS14-060	14	0.0470	60	0.6	4.29
GIS14-080	14	0.0627	80	0.8	5.71
GIS14-100	14	0.0784	100	1.0	7.14
GIS20-060	20	0.0960	60	0.6	3.00
GIS20-080	20	0.1280	80	0.8	4.00
GIS20-100	20	0.1600	100	1.0	5.00

[a*]Diameter of PP column, [b*]Volume of PP column over Volume of Kaolin Clay specimen, [c*]Height of column, [d*]Height of Column over Height of Kaolin Clay specimen, [e*]Height of Column over Diameter of PP Column

The unconfined compression test (UCT) is one of the most common tests in the industry to determine the undrained shear strength of the soil sample because it is simple and relatively less time consuming. This test is not suitable for testing the shear strength of sandy soil or soil that is not cohesive since these kinds of soil may fall apart right after the load is applied. The soil sample is only subjected to an axial force exerted by the compression machine during the testing.

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3. Results and Discussion

This section will discuss more on the result obtained from the laboratory testing. The effect of encapsulated PP column on the shear strength was discussed in detail below. In addition, the correlation equation obtained based on the result was also discussed below.

3.1. Effect of Encapsulated PP Column to The Undrained Shear Strength of Kaolin Clay

The results obtained from the UCT test were summarised in Table 5. Five (5) specimens were tested for each sample, and the shear strength of the sample can be obtained by taking an average of all 5 data. The shear strength, S_u, and shear strength improvement, ΔS_u for all samples are calculated and tabulated in Table 5.

Table 5. UCT Test Result.

Sample	V_c/V_s	H_c/H_s	Su (kPa)	$\Delta \boldsymbol{S_u}$ (%)
Control	0	0	25.22	-
GIS14-060	0.0470	0.6	33.75	33.82
GIS14-080	0.0627	0.8	36.95	46.51
GIS14-100	0.0784	1.0	37.80	49.88
GIS20-060	0.0960	0.6	31.58	25.22
GIS20-080	0.1280	0.8	33.64	33.39
GIS20-100	0.1600	1.0	34.70	37.59

3.2. Correlation of Column Penetration Ratio and The Shear Strength Improvement of Kaolin

The most effective height penetration ratio obtained in this study is 1.0. The percentage of shear strength improvement for different column parameters is shown in Table 5. A column with 100 mm height and 14 mm diameter gave the highest percentage of improvement, which is 49.88%, while a PP column with 60 mm height and 20 mm diameter gave the lowest percentage of improvement, which only raised the shear strength by 25.22%. According to this research, 14mm diameter PP column with 0.6 height penetration ratio gave 33.82% strength improvement while column with the same diameter but 0.8 height penetration ratio increased the shear strength of kaolin clay by 46.51%. The kaolin sample implanted with a 20 mm diameter had 33.39% strength improvement when the penetration ratio was 0.8 and enhanced the shear strength of kaolin clay by 37.59% when the penetration ratio was 1.0. The correlation of shear strength improvement and height penetration ratio of 14mm and 20 mm diameter can be determined from equation (1) with $R^2 = 0.9819$ and equation (2) with $R^2 = 0.9902$, respectively.

$$\Delta S_u = 53.24\ (H_c/H_s) + 1.2094 \qquad (1)$$

$$\Delta S_u = 38.773\ (H_c/H_s) + 0.7845 \qquad (2)$$

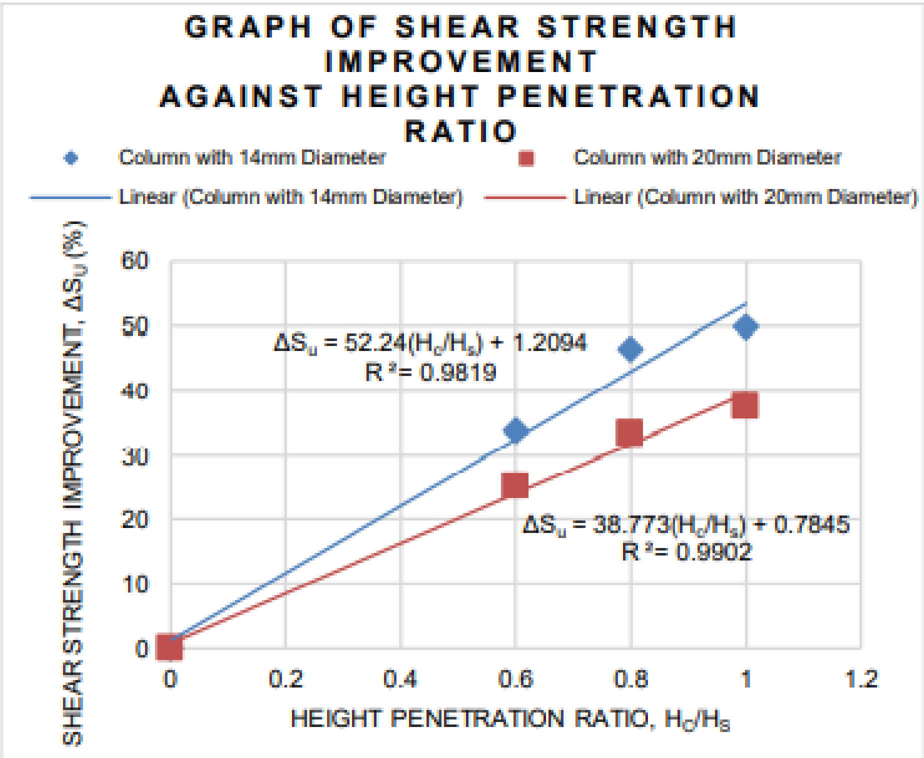

Figure 2. Graph of shear strength improvement against height penetration

3.3. Correlation of Column Height to Column Diameter Ratio and The Shear Strength Improvement of Kaolin

Based on the graph in Figure 3, the highest strength improvement occurred when the column height to diameter ratio was 7.14. On the contrary, the strength enhancement is the least when the column height to diameter was 3. It matches the result by Hasan et al. [8], which stated that the column height to diameter ratio was recommended to be within 4-8. The correlation equation for the 14 mm diameter column is stated in equation (3) with R2 = 0.9819. For the 20 mm diameter column, the correlation equation is as stated in equation (4) with the $R^2 = 0.9902$.

$$\Delta S_u = 7.3173\ (H_c/D_c) + 1.1989 \quad (3)$$

$$\Delta S_u = 7.7546\ (H_c/D_c) + 0.7845 \quad (4)$$

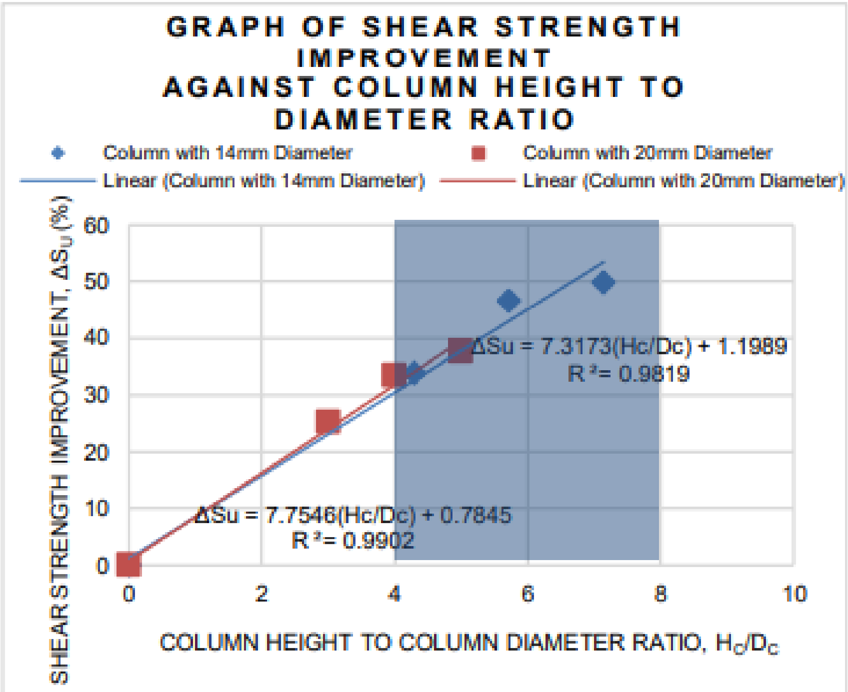

Figure 3. Graph of shear strength improvement against column height to diameter ratio

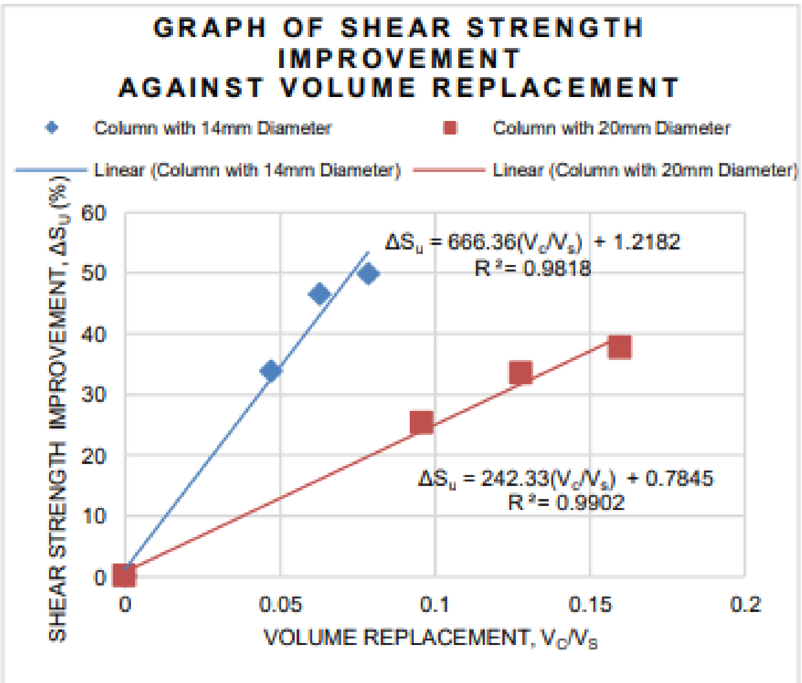

Figure 4. Graph of shear strength improvement against volume replacement

3.4. Correlation of Volume Replacement and The Shear Strength Improvement of Kaolin

Figure 4 shows the graph of shear strength against volume replacement ratio. The shear strength enhancement is not in line with the increase of volume replacement ratio. The correlation equations (5) and (6) were generated for columns 14 mm and 20 mm.

$$\Delta S_u = 666.36(V_c/V_s) + 1.2182 \quad (5)$$

$$\Delta S_u = 242.33(V_c/V_s) + 0.7845 \quad (6)$$

4. Conclusions

Based on this study, Kaolin clay used in this study is classified in class CL which is low plasticity under British Standard since the LL is 34.41% which is smaller than 35%. The PL for the soil sample is 24.4%, while the PI value is 10.01%. The maximum dry density of 1.60 Mg/m^3 can be reached when 19% of water is added to the clay sample. The specific gravity of the soil sample is 2.60, and the permeability of the kaolin clay is 8.45 $x10^{-11}$ m/s. The size of granular PP is ranged from 1.18- 3.35 mm and has a maximum dry density of 0.75 g/cm^3 and minimum dry density of 0.56 g/cm^3. The other parameters are obtained from Titan Petchem (M) Sdn. Bhd.

This study proved that the addition of a PP column is effective in treating problematic soil. The most effective height penetration ratio, H_c/H_s obtained in this study is 1.0. Columns with 100 mm height and 14 mm diameter gave the highest percentage of improvement, 49.88%. The shear strength improvement for 0.6 and 0.8 height penetration ratios is 33.82% and 46.51%, respectively. For the PP column with a 20 mm diameter with a 0.6, 0.8 and 1.0 height penetration ratio, the improvement is 25.22%, 33.9%, and 37.59%.

The highest strength improvement occurred when the column height to diameter ratio was 7.14. The shear strength improvement was the lowest when the column height to diameter ratio was 3. Therefore, it can be concluded that the critical length for the PP column, H_c/D_c ratio falls between 4-8, which is the recommended value [4].

Acknowledgments

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