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BEARING CAPACITY OF SOFT CLAY INSTALLED WITH SINGULAR AND GROUP OF ENCASED BOTTOM ASH COLUMNS

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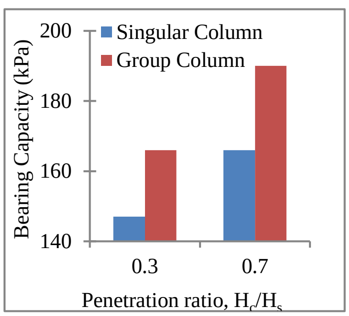
Graphical abstract



Abstract

Due to limited availability of construction site, many constructions are now carried out on site of poor ground condition, including on the soft soils. Vertical stone column technique has proven capable to increase the shear strength of soil and drain out water from the ground, decreasing the settlement of the structure. It is believed that the utilisation of coal ash as alternative material in constructing stone column can contribute to a more sustainable construction environment. This paper aims to investigate the improvement of bearing capacity of soft kaolin after installing with singular and group of encased bottom ash column using physical modelling. The white kaolin S-300 was used to represent the soft clay while bottom ash obtained from Tanjung Bin Power Plant, Johor was used in the construction of the stone column. The presence of bottom ash stone column has significantly increased the bearing capacity of kaolin clay. The increment of the bearing capacity in soft kaolin clay is higher when it is reinforced with group of bottom ash column and when the penetration ratio is larger. The penetration ratio showed more significant influences to the bearing capacity of soft kaolin clay as compared to the number of bottom ash column installed in soft kaolin clay.

Keywords: Stone column; penetration ratio; kaolin; physical modelling

1.0 INTRODUCTION

The urbanisation development runs extensively in Malaysia, the number of housing, commercial, industrial and other infrastructure developed massively through years. Due to limited availability of construction site and price of land keep on increasing, construction now carried out on site with poor ground condition, including on the soft soils which having the undrained shear strength less than 25 kPa. The soft soil is not only having a very low bearing capacity, but also having low permeability and high compressibility. Constructing building or structure on poor ground such soft soil will affect the settlement and stability of the structure.

In order to ensure the serviceability of the construction built on top of soft soil, soil improvement using various kinds of method is a must. One of these soil improvement methods is the utilisation of stone column in soft clay. Stone column that consist of granular material compacted in long cylindrical holes is used as a technique for improving the strength and consolidation characteristic of soft clay. From previous study, vertical granular column technique has proven capable to increase the shear strength of soil and drain out water from ground in result to decrease the settlement of the structure. However, vertical granular column such as stone column technique will have low lateral confinement, stone column encounter excessive bulging, and squeezing of soft soil into the column. Initiative to that problem, geotextile is used to enhance the performance of the column.

In Malaysia, the generation of electricity using coal burning has produced abundant of coal ash, in the forms of fly ash and bottom ash. Wastage or residue in coal fired power plant especially bottom ash has become a big problem, in particular for the disposal of the waste. To generate large amount of electricity, massive amount of bottom ash are produced. Large area of landfill must be provided to disposing the bottom ash. This has become major problem to our environment especially in term of sustainability. Instead of providing the more area for disposing the wastage, it can be used as replacement to natural resources. It is believed that the utilisation of these by-products (coal ashes) in soil improvement can contribute to a more sustainable construction environment. For example, coal ash had been used as the backfill material in embankment construction [1]. Generally, the physical properties of bottom ash are porous, coarse, and granular; which is similar to the physical properties of natural sand [2]. Thus, it is hypothesise that bottom ash could be used as the alternative material to constructed as the stone column. The installation of stone column can significantly increase the shear strength of soft kaolin but largely depends on the column penetration ratio, as summarised in Table 1 [3]. It is suggested that the "critical column length" falls between four to eight times the column diameters. Beyond the critical length, the penetration ratio may no longer participate in increasing the load carrying capacity of soft clays. A long stone column having a length greater than its critical length fails by bulging irrespective to whether it is end bearing or floating [4]. As the installation of bottom ash stone column shows great improvement in terms of shear strength, this paper aims to investigate the improvement of bearing capacity of soft kaolin after installing with singular and group of encased bottom ash column(s) with different penetration ratio.

Table 1 Shear strength improvement of soft clay reinforced with singular and group of uncased bottom ash column(s) at different penetration ratio [3]

No of Columns	Penetration Ratio Hc/Hs	Improvement of shear strength (%)
1	0.6	39.72
1	0.8	166.72
1	1.0	64.11
3	0.6	45.86
3	0.8	134.05
3	1.0	61.96

Note: Hc – Height of column Hs – Height of sample

2.0 LABORATORY TESTING

In order to determine the bearing capacity of soft clay reinforced with singular and group of encased bottom ash columns, physical modelling was used. Prior to the physical modelling, the physical and mechanical properties of bottom ash and white kaolin was determined through index tests including Atterberg limits, specific gravity, standard compaction and particle size distribution test.

3.1 Material

The white kaolin S-300 bought from Kaolin (M) Sdn. Bhd., Selangor, was used to represent the soft clay while bottom ash obtained from Tanjung Bin Power Plant, Johor was used to construct as the stone column. This power plant is owned and operated by Tanjung Bin Sdn. Bhd. which is the subsidiary of Malakoff Bhd. based in Kuala Lumpur, Malaysia. Polyfelt TS20 was used as the geosynthetic encasement for the bottom ash columns.

3.2 Soil Index Test

The soil index tests that carried out were the determination of Atterberg limits, particle size distribution and specific gravity. All soil index tests were performed in accordance with BS 1377:1990 Part 2. The standard compaction test was also carried out in accordance with BS 1377:1990 Part 4. These tests were performed on both kaolin and bottom ash.

3.3 Physical Modelling

A rigid box having dimension 400 mm length, 150 mm width and 430 height was prepared for soft ground model. Three side of the box are made from aluminium and the front side of the box has a removable 20 mm thick Perspex panel to allow real time visualization of soil movement during testing. All side are fixed tightly which prevented lateral movement during the consolidation of the model and loading of the footing. The mild steel footing size used was 150 mm length, 100 mm width, and 20 mm depth. Figure 1 shows the model of the testing chamber.

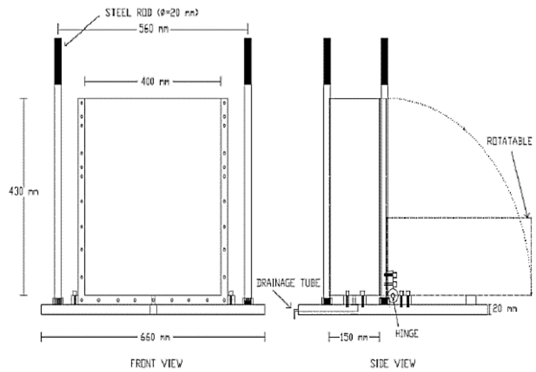


Figure 1 Model testing chamber

A total of five load tests were carried out on kaolin soil samples with a dimension of 400 mm length, 150 mm width and 200 mm height to observe the bearing capacity of kaolin soils at different testing condition, as summarised in Table 2.

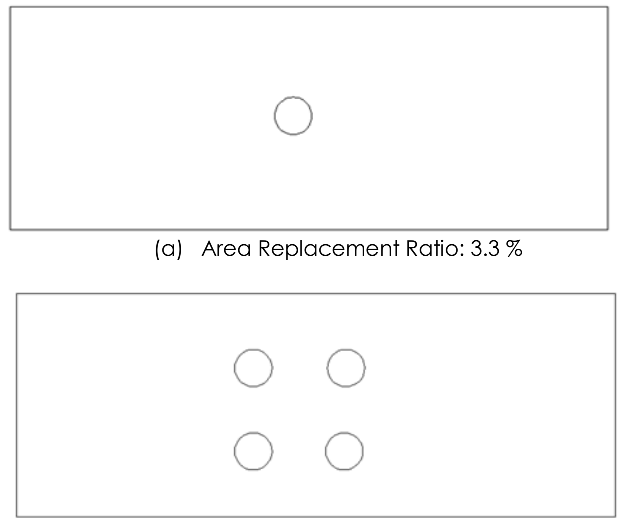
Table 2 Testing programme of load test

Test Series	Reinforced with bottom ash stone column	Penetration ratio
0C:0PR	No	No
1C:0.3PR	Single	0.3
1C:0.7PR	Single	0.7
4C:0.3PR	Group (4)	0.3
4C:0.7PR	Group (4)	0.7

Kaolin Slurry was prepared in the consolidation chamber by mixing 29 kg of kaolin clay powder and 17 kg of the de-ionized and de-aired water. The kaolin powder and the water were poured into a mixing drum. Before mixing, the powder was slowly allowed submerged under the water to avoid spreading of dust. Slurry at just over 1.5 times the liquid limit was made up to produce a homogenous sample. The slurry was then mixed for 5 minutes before poured into the chamber. The sample then was consolidated for a week to achieve height of sample to 200 mm.

The diameter of the column (D) and the particle size of granular material (d) play an important role in choosing the appropriate size of the column to be used in model tests. According to previous researcher, it is desirable to have a ratio of D/d in model tests to be similar to that found in the prototype structures being modelled. The column diameter used in this study was 25 mm, while particle sizes of bottom ash are between 0.6 to 2.0 mm. Thus the ratio D/d in the model test is ranging from 12.5 to 41.6.

For installation of bottom ash columns in the physical modelling, 2 different arrangements were designed. Templates with predetermined drilled location in a rectangular pattern were made as guide for column installation and 40 mm distance between holes. Two types of templates were made with different area replacement ratios, a_p, of 3.3 % and 13.1 % as shown in Figure 2. Each of the arrangement will be practised with penetration ratio depth of 0.3 (60 mm) and 0.7 (140 mm). Polifelt TS20 was used as the encasement materials to help the formation of bottom ash column. The geotextile was sewed to form the casing before installed into the samples. Ten encasements were sewed for this study, which consists of length of 60 mm and 140 mm according to the ratio 0.3 and 0.7 penetration ratio. The diameter of each encasement is 25mm.



(a) Area Replacement Ratio: 3.3 %

(b) Area Replacement Ratio: 13.1 %

Figure 2 Arrangements of bottom ash column

There are several ways to determine the ultimate bearing capacity oh the soil. From the previous researcher, the allowable settlement was considered as 20 % from the width of the loading plate. The ultimate bearing capacity was taken on the strength correspond to the said settlement [5]. The mild steel footing was placed in position and the load was applied to it by mechanical jack through the proving ring. Before the test started, dial gauge was placed on the jack leg to monitor the settlement needed. The load was applied until the settlement occurs to be 20 mm. The load transferred to the footing was measured by a proving ring.

3.0 RESULTS AND DISCUSSION

3.1 Properties of Kaolin and Bottom Ash

The physical properties of kaolin and bottom ash were tabulated in Table 3. From the Atterberg limits test, the liquid limit and the plastic limit obtained for the kaolin are 38 % and 25 %, respectively. Based on the Unified Soil Classification System (USCS), the kaolin is classified as low plasticity clay (ML). The bottom ash shows non plastic behaviour. As for the specific gravity, the kaolin is having greater values as compared to bottom ash. The specific gravity of kaolin and bottom ash are 2.65 and 2.35, respectively. The content of iron oxide in the bottom ash influence the value of specific gravity obtained [6]. Low specific gravity resulted from high carbon content, whereas high iron content will give high specific gravity. Figure 3 shows the particle size distribution curves of kaolin and bottom ash. The kaolin is having particle size ranging from 0.001 mm to 0.200 mm while bottom ash is having particle size ranging from 0.063 mm to 20 mm. Based on the USCS, the bottom ash is classified as well graded sand (SW).

Table 3 Physical properties of marine clay

Properties	Results
Kaolin	
Liquid Limit	38%
Plastic Limit	25%
Plasticity Index	13%
Specific Gravity	2.65
Particle Size	0.001 – 0.200 mm
Permeability	3.4 x 10^{-9} m/s
Maximum Dry Density	1890 Kg/m^3
Optimum Moisture Content	19 %
USCS	ML
Undrained shear strength: 35% moisture content	10 kPa
Bottom Ash	
Specific Gravity	2.35
Particle Size	0.063 - 20 mm
Soil Classification (AASTHO)	A-1-a
Soil Classification (USCS)	SW
Permeability	1.28x10^{-4} m/s
Maximum Dry Density,	1338 Kg/m^3
Optimum Moisture Content	23 %

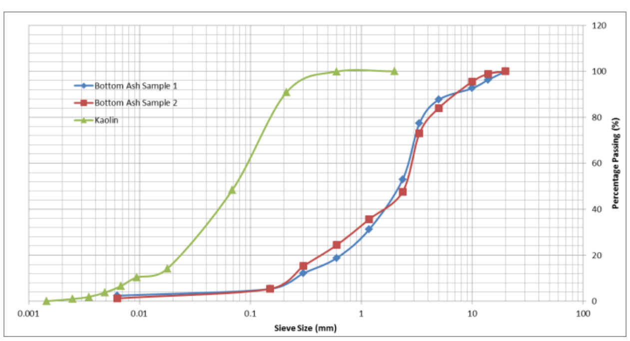


Figure 3 Particle size distribution of kaolin and bottom ash

3.2 Load Test

Figure 4 shows the actual physical model of kaolin clay encased with singe and group of bottom ash stone column. For both cases, the penetration ratio was varies at two different values of 0.3 and 0.7, particularly. The results of all five load tests were summarised in Table 4, particularly the bearing capacity of kaolin clay. The ultimate bearing capacity of the soil was determined at 20 % of the settlement ratio. Generally, the installation of bottom ash stone column increased significantly the bearing capacity of soft kaolin for about three to four times of the original bearing capacity of soft kaolin. The bearing capacity of soft kaolin reinforced with group of four bottom ash stone columns had higher bearing capacity than the soft kaolin reinforced with only one bottom ash stone column. This is because the greater the area of replacement ratio, the value of ultimate bearing capacity will increase [4], [7]. In addition, at similar numbers of bottom ash stone column, the increment of the bearing capacity is higher for the penetration ratio of 0.7, as compared to 0.3 penetration ratio.
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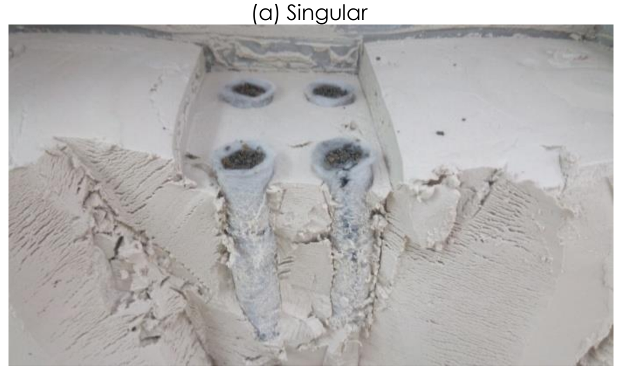
(a) Singular



(b) Group

Figure 4 Kaolin clay encased with bottom ash column

Table 4 Summary of the ultimate bearing capacity

Sample	Bearing capacity (kPa)	Percentage of increment (%)
0C:0PR	34	-
1C:0.3PR	147	332
1C:0.7PR	166	388
4C:0.3PR	158	365
4C:0.7PR	190	458

Figure 5 shows the bearing capacity of kaolin clay reinforced with bottom ash column. It can be seen from the figure that the 4C:0.7PR has the highest bearing capacity. The second highest bearing capacity is the 1C:0.7PR, and followed by 4C:0.3PR. The 1C:0.3PR has the lowest bearing capacity amongst of all four kaolin clay reinforced with bottom ash column soil specimen. Thus, this result showed that although the penetration ratio plays more important part than the number of installed bottom ash stone column in soft kaolin clay. This is because although 1C:0.7PR had only one bottom ash stone column, the bearing capacity is still higher than the 4C:0.3PR that consisted of four bottom ash stone columns.

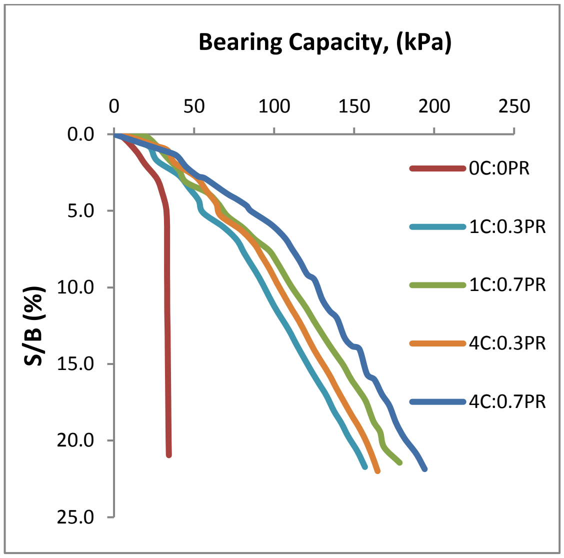


Figure 5 Bearing capacity of kaolin clay reinforced with bottom ash column

Figure 6 shows the bearing capacity of soft kaolin clay reinforced with single and group of four bottom ash stone columns determined at at 20 % of the settlement ratio. The figure demonstrated clearly that the more stone column installed in the soft kaolin clay, the more bearing capacity the soils had at similar penetration ratio. In addition, the higher the penetration ratio the bottom ash stone column installed to the soft kaolin clay, the higher the bearing capacity of the soils had at similar number of stone column. Between the two important factors (number of bottom ash column installed and penetration ratio), the penetration ratio showed more significant influences to the bearing capacity of soft kaolin clay as compared to the number of bottom ash column installed in soft kaolin clay. This is because the bearing capacity of 1C:0.7PR is slightly higher than 4C:0.3PR.

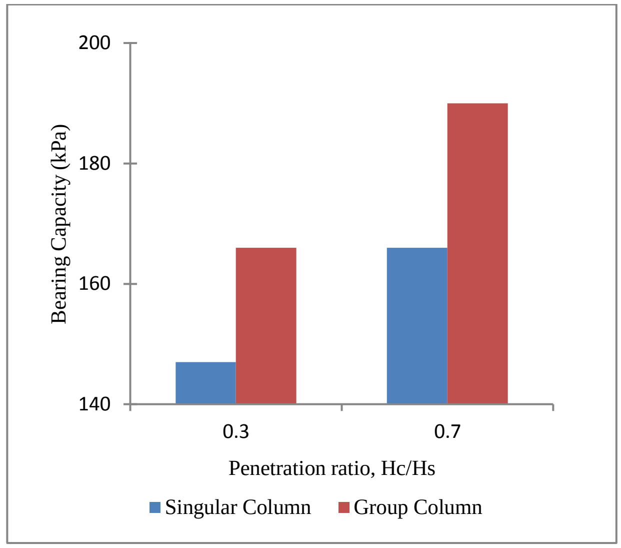


Figure 6 Bearing capacity at different penetration ratio

4.0 CONCLUSION

Based on the laboratory test that had been carried out in determining the engineering properties of kaolin and bottom ash as well as determining the bearing capacity of the soft clay installed with singular and group of encased bottom ash column(s), the conclusions drawn are as follows:

i. The presence of bottom ash stone column in soft kaolin clay has significantly increased the bearing capacity of kaolin clay. For singular column, the increment of ultimate bearing capacity increased from 34 kPa to 147 kPa (increment of 332 %) for 0.3 penetration ratios and to 166 kPa (increment of 388 %) for 0.7 penetration ratios. On other hands, for group columns, the increment of ultimate bearing capacity increased from 34 kPa to 158 kPa (increment of 365 %) for 0.3 penetration ratios and 34 kPa to 190 kPa (increment of 458 %) for 0.7 penetration ratios.
ii. The increment of bearing capacity in soft kaolin clay reinforced with group bottom ash stone columns is higher than kaolin clay reinforced with single bottom ash stone column.
iii. The increment of bearing capacity in soft kaolin clay reinforced with bottom ash stone column of 0.7 penetration ratio is higher than kaolin clay.
iv. The penetration ratio showed more significant influences to the bearing capacity of soft kaolin clay as compared to the number of bottom ash column (or area ratio) installed in soft kaolin clay.

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