wjert, 2018, Vol. 4, Issue 1, 376-392. *Original Article* ISSN 2454-695X

World Journal of Engineering Research and Technology
WJERT
www.wjert.org SJIF Impact Factor: 4.326

EXPERIMENTAL PLATE LOAD TEST ON MODIFIED STONE COLUMN IN EFFECTIVENESS OF ENHANCING BEARING CAPACITY OF COLUMN

Nazaruddin A. T.[1*], Zainab M.[2] and Hafez M. A.[3]

[1]Lecturer, Faculty of Engineering, University Malaysia Sabah, 88450 Kota Kinabalu Sabah, Malaysia.

[2]Lecturer, Faculty of Civil Engineering, University Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.

[3]Associate Professor, Faculty of Engineering, University Tenaga Nasional, 43650 Bangi Selangor, Malaysia.

Article Received on 20/11/2017 Article Revised on 11/12/2017 Article Accepted on 01/01/2018

***Corresponding Author**
Nazaruddin A.T.
Lecturer, Faculty of Engineering, University Malaysia Sabah, 88450 Kota Kinabalu Sabah, Malaysia.

ABSTRACT

According to previous studies, conventional stone columns have limitation on extremely soft soil due to lack of bonding among the particles of stone. Since many years ago, most of researchers have attempted to solve this problem and one of the solution was using mixed material such as cement to prevent bulging problem on stone columns. However, by implementing use of cement in stone column, it may solve problem related with bulging problem, but also cause the other problem such as increasing the cost of construction. By using waste materials such as fly ash is another solution to solve the problem. Fly ash is a solid waste material which produced from burning coal for energy sources. As a replacement material for cement among the usage of fly ash that has been applied in concrete technology. The study is continuation from previous article published by Author. Based on previous article, Universal Compression test (UCT) and Big Shear test were conducted. Result shows by using 70% of PFA, has gave the high of compressive strength and by using 60% of PFA, was the highest of interface shear strength. Thus, three configurations; 70%, 50%, 90%, 55%, 65% and 75% were chosen to be tested in this study under plate load test. The sample of all columns been tested in isolated clay model. Unit cell theory applied by using steel plate with size of 2 times of diameter column.

KEYWORDS: Pulverized Fly Ash (PFA); conventional stone column (CSC); Pulverized Fly Ash Stone Column (PFA SC); Plate Load Test; Bearing Capacity.

INTRODUCTION

In Malaysia, electricity generation from coal has grown at a rate of 9.7 percent per year and is predicted to increase substantially to meet the rising of demand for energy. Industrial sector domains the electricity demand which increase at 5.4 percent annually [Martunus et. al, 2008; APERC, 2006,]. According to the Asia Pacific Energy Research Center (APERC) cited from Inside Malaysia report, among the energy sources, coal is expected to grow rapidly in Malaysia in years soon, with predicted growth in demand 9.7 per cent between 2002 and 2030. The total coal consumption for electricity generation in Malaysia is projected to increase from 12.4 million tons in 2005 to 36 million tons in 2020. One of the power plants supplied electricity for Klang valley area is Sultan Abdul Aziz Shah Power Plant, located at Kapar, Selangor. In estimation, this power plant is using 100 tons' coal per hour to generate 1200 MW for the national grid. As a result, it produces 15 to 20 ton of Pulverized Fuel Ash (PFA) per hour. Millions of tons of PFA produced each year due to the massive consumption of coal [Khairul et. al, 2007]. Coal ash has contained toxic metal material such as thallium, barium, cadmium, chromium, mercury, and nickel. Without progressive measures for the disposal of coal ash, it can lead to groundwater contamination and air pollution. PFA is one of the fly ash that can be categorized in two types of class; Class C (burnt lignite and sub-bituminous coal) and Class F fly ash (burnt bituminous coal). There is plenty of researches have been done to explore the uniqueness and benefit inherent in coal fly ash and one of the researches is by using fly ash in replacing of cement in concrete and geotechnical soil stabilization. PFA is a most suitable fly ash in the process to replacing of cement due to its content higher Al, Si and Ca compare with the other type of fly ash. Because it contains higher ratio of Al, Si and Ca, the Pozzolanic process will be smoother and will stabilize soil better than with other types of fly ash. As additional, fly ash that categorized under Class F does not have the ability to be a binder in concrete material as well as it lacks effect on soil stabilization [Geliga et. al, 2010].

Stone Column and Application of PFA

Nowadays, the Soft ground problem is the most demanding challenges in the construction field. Dynamic compaction, stone column, jet grouting, lime stabilization, short pile, compaction grouting and vertical drainage are among of familiar ground improvement method. Selection of these methods are referred on improvement soil layers, but some cases refer on improvement rock layers [Masoumeh & Behzad, 2012; Rudrabir & Kashliwal, 2008]. Stone columns are the most cost-effective and simple installation than other methods. Stone columns can be defined as the vertical columns of compacted aggregate are through the soils to be improved. Despite that, it also has limitation. The effectiveness of stone columns depends on two main factors; stiffness of column material (such as crushed stone, sand, gravel, etc) and densification of surrounding soil during the installation of stone column [Deb & Pal, 2014; Isaac & Girish, 2009]. Other than that, the stone column has become most effective for soft soil with undrained shear strength ranging from 25-50 kPa. However, Stone column also have certain limitation due to the application on more compressible soils such as peat and sensitive clay [Juran & Guermazi, 1988; Arun et. al, 2012]. The main problem of stone column application is bulging failure. This particular failure occurs when lacking material strength used and absence on lateral restraint between the column and surrounding soil [Masoumeh & Behzad, 2012]. The unit cell concept is one the method has used in designing stone column under rigid foundation road embankment [Barksdale & Bachus, 1983]. The idea is considering the influence area of soil surrounding isolated column such shown in Fig. 1. According to previous studies, idealization of unit cell concept in laboratory work has demonstrated the reliability on design application [Ambily & Gandhi, 2007].

In this study, universal compression test has been used to identify the optimum content fly ash through in terms of strength and economic viability. The data also will be used in the further investigation for Modified Big Shear Box and Plate Loading Test for determination of bearing capacity of PFA-concrete pile. From the previous paper, author has done plate load test by using kaolin as a soil bed. In that paper, the isolated conventional stone column has been compared with 65% of PFA-concrete column. The result indicates that stone column is a lacking performance in soft soil compared with PFA-concrete column. Application on floating columns design, interface behaviour plays the vital role in determining load capacity. Modified Big shear box test was conducted to study the performance of interface shear strength PFA concrete with soft clay. From the results were obtained found that all the configurations cement shows the slight difference among them [Nazaruddin et. al, 2013;

Nazaruddin et. al, 2014]. Thus, purpose of this paper to study the performance of the selected configurations of PFA-stone column on actual soft soil.

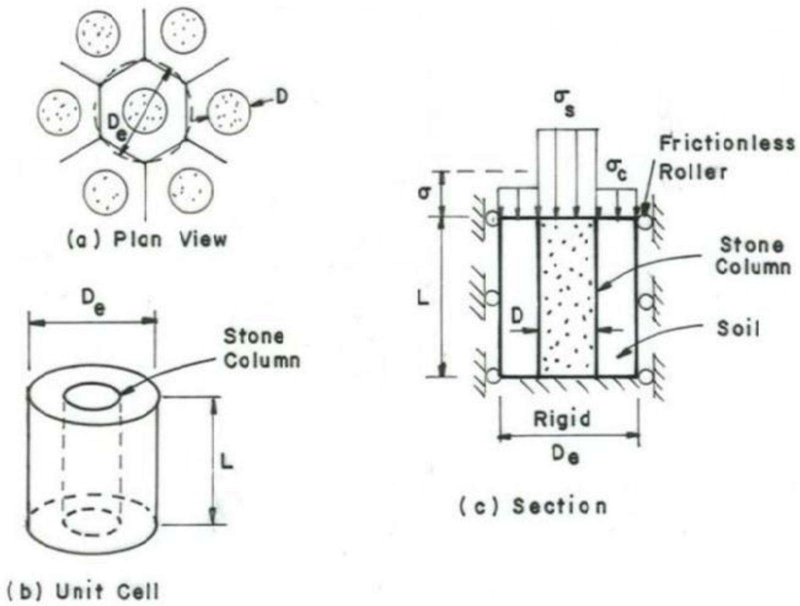

Fig. 1: Idealization of unit cell concept [Barksdale & Bachus, 1983].

Table 1: Chemical Composition of Pulverized Fly Ash (Class F) [Khairul et. al, 2007]

Composition	***Percentage %***
CaO	2.00
SiO_2	48.0
Al_2O_3	17.0
Fe_2O_3	2.70
MgO	0.29
SO_3	0.30
K_2O	0.64
Na_2O_3	0.16
Loss on ignition, LOI	8.30
Density (g/cm3)	2.17
$SiO_2 + Al_2O_3 + Fe_2O_3$	67.7

EXPERIMENTAL

In this study, there are ten (10) configuration of design mixture for modified stone column such explained in previous paper [Nazaruddin et. al, 2013]. Each configuration has three samples were prepared. The average results of three samples considered as the value of compressive strength. To control the environment and eliminate the effect of changes on moisture content and temperature, all the samples were immersed in the water for curing process. There were four periods for curing process; 1 day, 7 days, 14 days, and 28 days before the samples tested under UCT. The purpose is to study the development of compressive strength of each configuration sample within 1 day, 7 days, 14 days, and 28 days. Figure 2.0 shows the Unconfined Compression Test (UCT) machine that been used for testing the sample. In normal design pile, Determination of bearing capacity of floating pile based on the skin resistance between the material pile and the surrounding soil. By using shear box test, parameters that involved for skin resistance can be identified. The procedure of preparing samples and testing were explained in previous study [14]. In shear box test, only 28 curing days applied on each configuration to be tested. Figure 3.0 indicates the samples and the big shear box machine. The result obtained from both test used to select the onfigurations to be tested on plate load test.

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Fig. 2: Universal Compression Test (UCT).

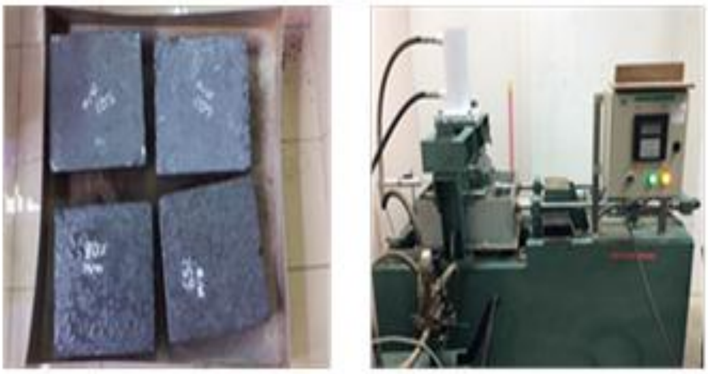

Fig. 3: Modified big shear box test.

Preparation of soil bed (Tank model) Natural soft soil Klang was used in all experimental work as the medium soil model in this study. The soft soil was collected from the construction sites at surrounding of coastal area of Jetty Nelayan Sementah about 10 kilometers from Klang main city. Table 2.0 indicates the properties of soft soil sample and Figure 4.0 shows the particle distribution of soil. Model tank used was made from steel plate for the three sides and the bottom floor of tank. While another one side was made by Perspex. Size of model tank has used is about 1.5m height, 0.8m width and length. Fully saturated Soil sample was placed in the tank as 1.2m height with clearance 0.3m at the top of tank. From two group of 10% and 5% cement content, three configurations from each group (the highest, intermediate and the lowest from the results test of UCT and big shear box) tested under plate load test. The six (6) sample have been compared with the soft clay alone and conventional stone column. All the samples for plate load test has been conducted in the geotechnical model tank. Therefore, eight (8) tanks were prepared for this test. To reduce the air gap in the soil bed, the plate made from wood was used to bulldoze the soil every 300mm height. Process of pre-consolidation was conducted for each model soil bed by using spring consolidation cushion for 7 days. This process was complying the spring analogy which is an idealized system composed of springs, a container with a hole in its cover and fully saturated soil. Afterwards, an axial load was applied on the cover of the spring until the settlement achieved 10mm the loading process turned off. Thus, the spring would undergo the expansion due to its own kinetic energy and will transferred for further compress to the soil bed. After 7 days, the spring cushion was removed and vane shear test will be take over.

Table 2: Soft soil properties used as soil bed.

Soil properties	
Plastic Limit	22%
Liquid Limit	31%
Water content	79.71%
Undrained Shear Strength	4 – 5 kPa
Specific Gravity	2.67

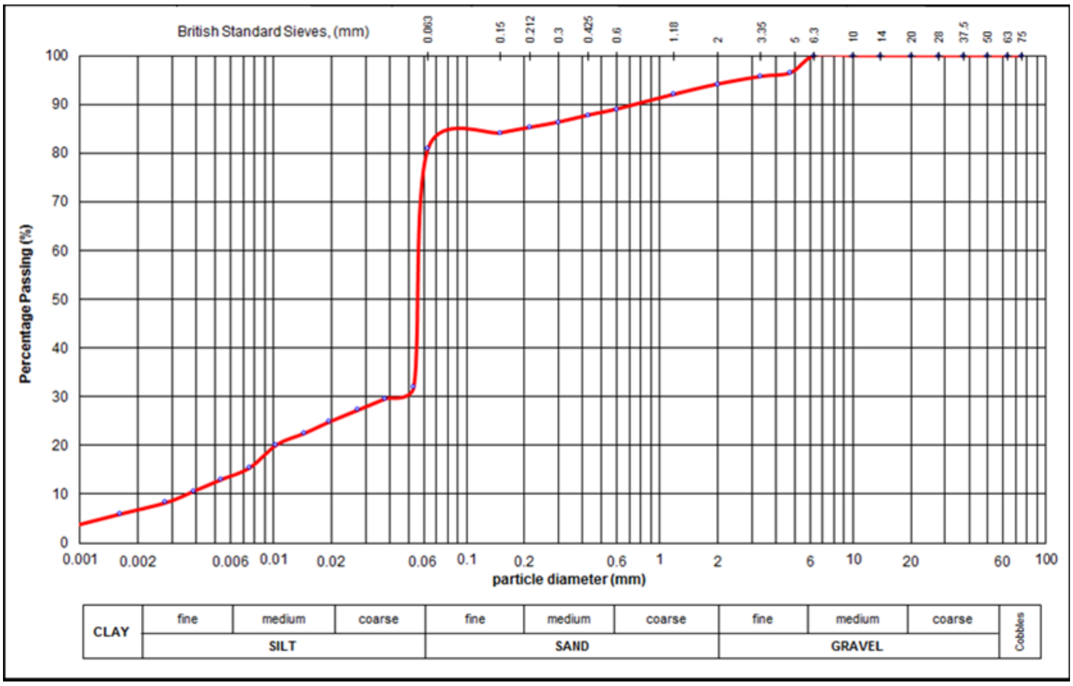

Figure 4.0: Percentage passing of particle distribution.

Column installation

PVC pipe with diameter 150mm and length 1 m, and Auger with 150mm head size used for installation of columns. Before drilling work started, the soil bed was marked properly at the center. This purpose is to avoid the installed column not parallel with the loading frame system. The drilling work started by pressing the PVC pipe at center of soil bed until fully sink 0.9m depth. Then, auger was used to remove the soil inside the pipe. Material mixture such aggregate, sand, pulverized fly ash and cement mixed using mixer machine before pouring inside the PVP pipe. The step repeated for all configuration have chosen for plate load test. Afterwards, all the installed PFA SC were left for 28 days before test conducted.

Experimental set up

Model tank used in this study was made with modify I-Beam steel frame for supporting loading system. Two steel columns were attached on the wall and slab tank to hold I-Beam steel frame. Electric power motor with 9.4 hp power was placed on the I-beam frame used for loading progress. And speed of loading applied was 0.5mm/min. To connect electric motor with load cell and steel plate, round steel rod with modify connection rod used to hold load cell at the middle. Figure 6.0 indicates the set-up of rod connection. Settlement transducer placed on the steel plate and hold with the magnetic rod to ensure no movement on transducer. Afterward, load cell and transducer connected to data logger with computer set for transferring data process. Figure 5.0 shows the illustration of typical model tank used in this study. Loading progress was turned off until 100mm settlement for data collection.

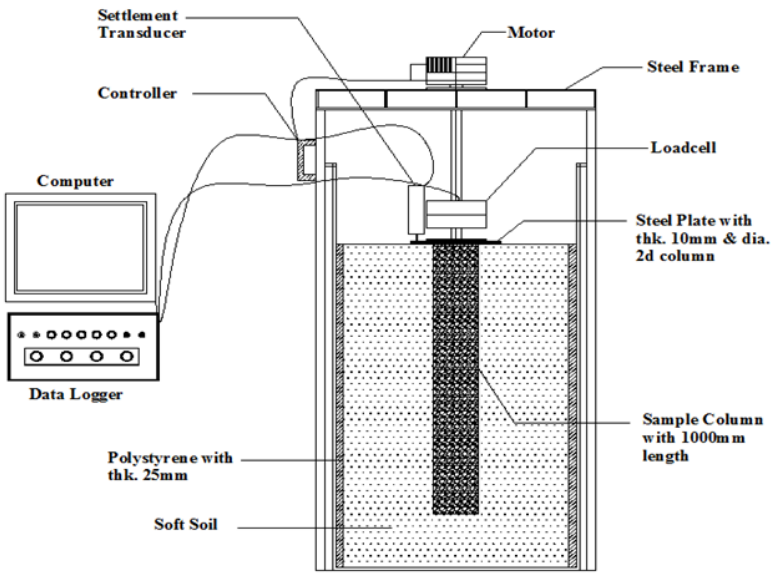

Fig. 5: Illustration of model tank for plate load test.

Fig. 6: Sample column after installation and plate load test.

RESULT AND DISCUSSION

Unconfined Compressive Strength

Unconfined compressive test (UCT) was carried out to the performance of each configuration on compressive strength. In previous paper explained that with 10% and 5% cement content show all the compressive strength increase as well as curing day. Table 5.0 and 6.0 indicate the results of compressive strength with curing days. In early stage for 10% cement indicates that significant increment on compressive strength. It is difference with 5% cement have risen gradually. On the 14th until 28th day, the increment of strength has slowed down, particularly for 10% cement content. Only for 65%pfa has increased steadily until 28th day. The increment of strength occurs due to the hydration process in the early age stage and it is will continually if the pozzolanic reaction still in taking place. For 10% cement content at 28th curing day, Sample with 70%pfa has produces the highest compressive strength about 4.23 MPa and the lowest is about 4.023 MPa obtained from 50% pfa sample. While, there are changes occur when cement content reduced for 5% with sample of 65% pfa have the highest compressive strength about 2.444 MPa and 1.603 MPa from 95%pfa is the lowest [Nazaruddin et. al, 2013].

Table 3.0: Compressive strength for 10% cement configurations.

Average Maximum Compressive strength for 10% Cement (Mpa)					
Curing Days	**50%PFA**	**60%PFA**	**70%PFA**	**80%PFA**	**90%PFA**
1	0.957	0.848	0.798	0.823	0.891
7	1.797	1.775	2.146	2.132	2.214
14	2.983	2.714	3.755	3.953	3.984
28	4.023	4.092	4.23	4.122	4.148

Table 4.0: Compressive strength for 5% cement configuration.

Average Maximum Compressive strength for 5% Cement (Mpa)					
Curing Days	**55%PFA**	**65%PFA**	**75%PFA**	**85%PFA**	**95%PFA**
1	0.762	0.703	0.559	0.527	0.518
7	1.288	1.27	0.966	0.855	0.813
14	1.476	1.471	1.373	1.261	1.198
28	1.989	2.444	1.783	1.709	1.603

Interface Shear Strength

Table 5.0 and 6.0 show the value of interface shear strength parameters for all configurations. From the results, distinction between samples with 10% cement and 5% cement only within the range below 5.5% for interface angle friction value. Sample of 60%pfa has produces the highest value of friction angle with 27.61^0, while sample with 85%pfa is the lowest. In terms of cohesion C, show the significant difference between 10% and 5% cement content particularly for 50%pfa with 55%pfa, 60%pfa with 65%pfa and 90%pfa with 95%pfa about in range 30% to 44%. Otherwise for 70%pfa and 80%pfa those only have a slight difference with 75%pfa and 85%pfa respectively which below 5%. It can be seen adequate mixing of sand, PFA, cement and aggregate play vital role for interaction interface sample with the soil.

Fly ash has fineness particles compare to sand and cement. With huge amount of fly ash, it could fulfill space among the particle of aggregate. Although present of fine aggregate such as sand can increase the strength of interlocking among the particles of stone. For any design, which not truly refer to the strength but more to the economical, PFA could be as a part of the solution [Nazaruddin et. al, 2014].

Table 5.0: Properties of interface shear strength for 10% cement configurations.

Configuration	Cohesion (kN/m^2)	Interface friction angle (δ^0)	Interface shear strength (kN/m^2)
50%PFA	8.73	25.47	42.72
60%PFA	8.6	27.61	45.85
70%PFA	11.17	23.66	42.54
80%PFA	11.64	22.46	41.26
90%PFA	3.84	25.26	37.54

Table 6.0: Properties of interface shear strength for 5% cement configurations.

Configuration	Cohesion (kN/m^2)	Interface friction angle (δ^0)	Interface shear strength (kN/m^2)
55%PFA	6.15	24.4	38.58
65%PFA	7.14	27	43.46
75%PFA	10.71	22.35	40.17
85%PFA	11.31	21.68	39.81
95%PFA	2.16	25.3	35.92

Plate Load Test

There are 8 samples tank were used for plate load test. From the observation shows that by reinforcing soft soil it can improve the load capacity behavior. Previous studies stated that stone column method has limitation in extremely soft soil with undrained shear strength below 10 kPa. It is proven from this study shown in Figure 7.0 shows that by using conventional method stone column has less improvement to enhance for load compare to all semi rigid column samples. In this test, the highest and the lowest compressive strength have been selected for each group cement content 70%PFA was the highest in 10% cement content group. Meanwhile, 65%PFA the highest in 5% cement content group. Then 90%PFA and 95%PFA are the lowest for 10% and 5% cement group respectively. To ensure the effect of sand content, configuration of 50%PFA and 55%PFA have chosen. From the graph indicate that different configurations of PFA mixture give are substantially difference performance. 70% PFA content has shown the highest load capacity from the others whereas 95% PFA content showed a contrary result. For data analysis from the load-settlement graph result, method Idealization of straight line by [Golait & Satyanarayana, 2009] was used in this study to carry out the analysis and interpretation of load settlement data of each configuration. The system was using double tangent method which the point of intersection of two tangents straight line considered as failure load capacity. Each sample were assumed as a unit cell sample to adopt the similar procedure to all sample Figure 8.0 shows that the load-settlement graph result of 50%PFA sample analyzed using method by [Golait & Satyanarayana, 2009]. Then, 2/3 of load capacity failure (Q_f) used for analysis of settlement performance such shown in Figure 9.0. All of interpretation data from load-settlement graph results tabulated in Table 7.0. From the result, untreated soil was failed at 18mm settlement with load failure 1.74 kN. Meanwhile for conventional stone column at 36mm settlement failed under 2.59kN load. For column with 10% cement content; 50%PFA, 70%PFA and 90%PFA were failed at around 16mm and 19mm settlement with loading failure 3.42kN, 3.87kN and 2.95kN respectively. For 5% cement content; 55%PFA, 65%PFA and 95%PFA were cater lower loading capacity compare to the 10% cement content unit cell. 55% PFA was failed at 16mm with load 2.47kN, meanwhile 2.82kN load capacity failed at 20mm settlement for 65%PFA. And for 95%PFA failed at 18mm settlement with loading failure 2.46kN. In this study, all the load failure data used to determine the coefficient of bearing capacity Meanwhile for the straight line obtained from 2/3 load failure used for settlement performance.

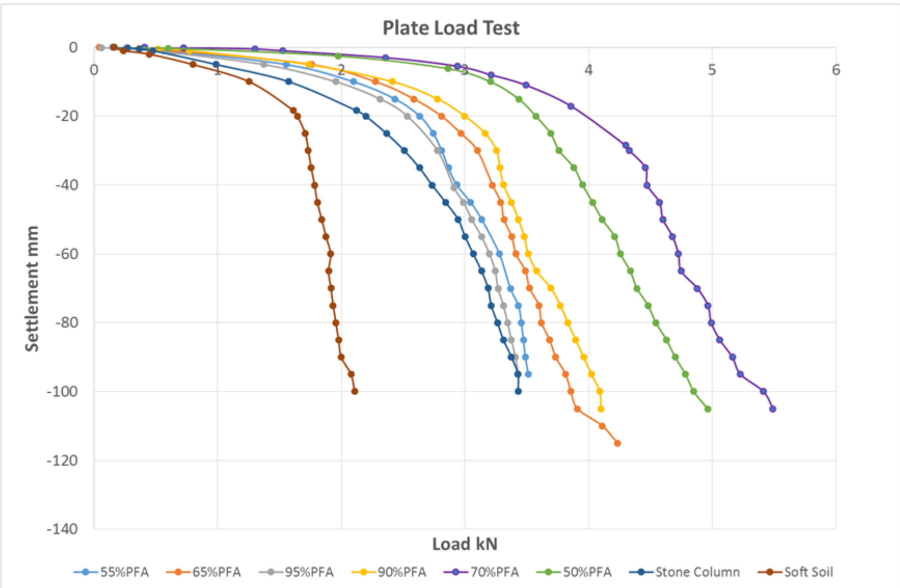

Figure 7.0: Plate load test results.

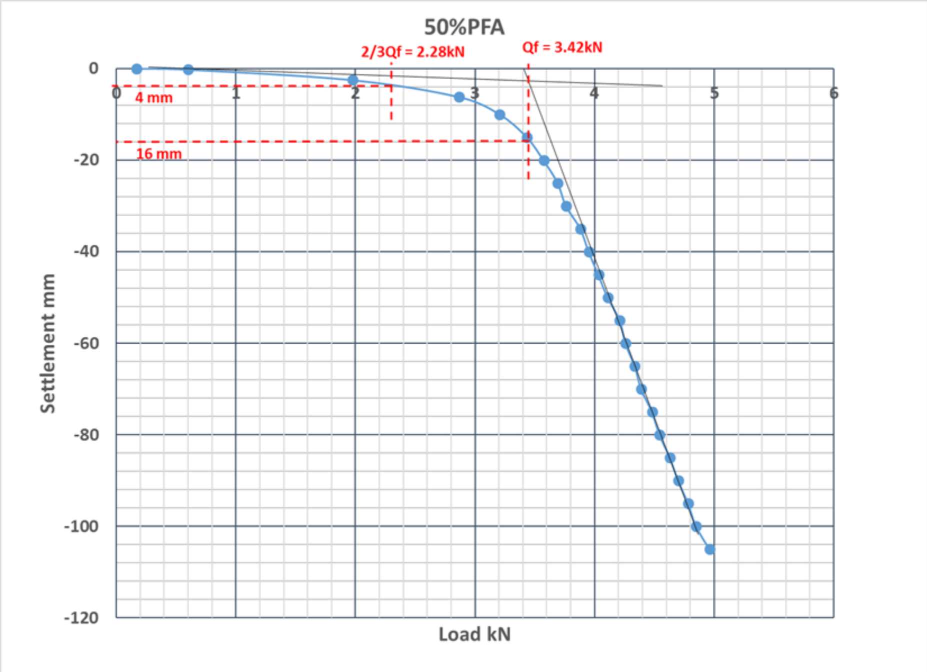

Figure: 8.0: Load versus settlement for 50%pfa column.

Table 7.0: Interpretation plate load test results for each sample.

Sample	Load Failure (Q_f kN)	2/3 Load Failure ($2/3Q_f$ kN)	Settlement at 2/3 Q_f (s mm)
Soft soil alone	1.74	1.16	10
Stone column	2.59	1.73	12
50%PFA column	3.42	2.28	5
70%PFA column	3.87	2.58	5
90%PFA column	2.95	1.97	6.5
55%PFA column	2.47	1.65	6
65%PFA column	2.82	1.88	6.5
95%PFA column	2.46	1.64	7

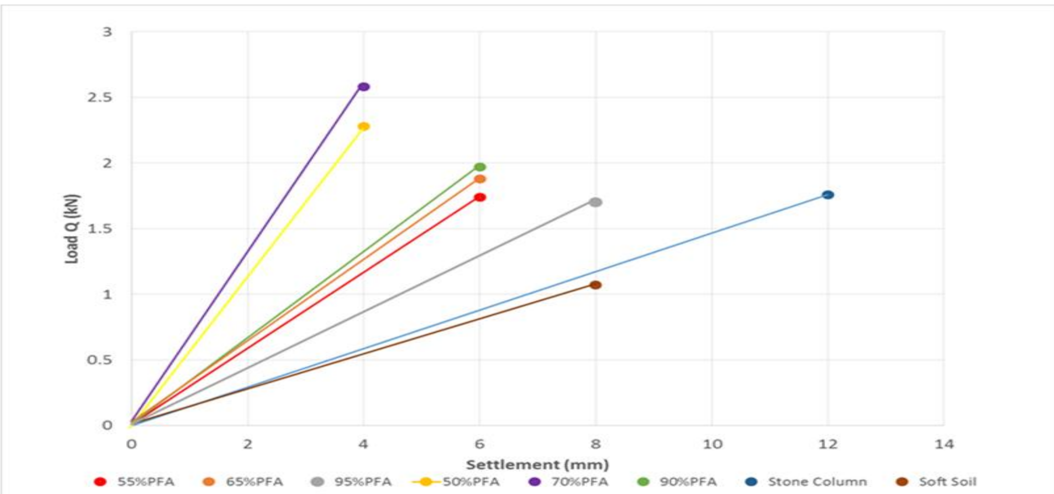

Figure 9.0: Linear idealization of $2/3Q_f$ for each sample.

Settlement Improvement Ratio

Settlement improvement factor of a unit cell system is depending on the stiffness of unit cell that contain a column (stone column or PFA-column) and surrounding soil. Unit cell stiffness can be determined through first linear line which the value of 2/3 loading capacity failure divided with the settlement of loading base such as shown in Equation (1) and defined as loading pressure per unit settlement, k. Table 8.0 shows the stiffness value of each unit cell sample.

$$k = \frac{Loading\ pressure}{Settlement\ of\ loading\ base} = \frac{kN/m^2}{m} = \frac{P}{\delta} \quad \text{Equation (1)}$$

Table 8.0: Stiffness of each sample.

Sample	Loading Pressure, P (kN/m^2)	Stiffness, k (kN/m^3)
Soft soil alone	16.411	1641.06
Stone column	24.427	2035.61
50%PFA column	32.255	6451.08
70%PFA column	36.500	7299.91
90%PFA column	27.823	4280.41
55%PFA column	23.296	3882.59
65%PFA column	26.597	4091.78
95%PFA column	23.201	3314.46

To obtain the settlement improvement factor (n) of each unit cell, the stiffness of treated soil unit cell divided with the stiffness of untreated soft soil unit cell such as shown in Equation (2). And Table 9.0 indicate the settlement improvement ratio result of each unit cell sample.

$$n = \frac{stiffness\ of\ treated\ soft\ soil}{stiffness\ of\ untreated\ soft\ soil} = \frac{k_c}{k_s} \quad \text{Equation (2)}$$

Table 9.0: Settlement improvement ratio (n) of each sample.

Sample	Settlement Improvement Ratio (n)
Soft soil alone	1.00
Stone column	1.24
50%PFA column	3.93
70%PFA column	4.45
90%PFA column	2.61
55%PFA column	2.37
65%PFA column	2.49
95%PFA column	2.02

Production of calcium aluminate silicate hydrate CASH and calcium silicate hydrate from pozzolanic and cementation reaction which migrate to surrounding soil form has increase the strength of soil matrix (change of properties of soil). This will contribute in reduction settlement of soil treated. Other than that, the cohesion of between column sample surrounding soil also improved. However, all of this was depending on the amount of CASH and CSH produced. In this study, sample with 70%pfa show the greater performance in reduction of settlement of treated soil. 50%pfa was the second highest behind 90%pfa. In 5% cement group give the result 65%pfa sample more perform on reduction settlement compare to 55%pfa and 95%pfa. And for conventional stone column shows the lowest value of settlement improvement factor. Due to lack of bonding among in the stone column material, bulging failure was take over to sustain the vertical load and causes a slight value of settlement improvement factor.

Bearing Capacity Improvement Factor (F_b)

Coefficient of bearing capacity treated soil (N_{ct}) can be measured by coefficient of natural soil bearing capacity (N_c) times with improvement factor (F_b) such shown in Equation (3). Bearing capacity improvement factor can be defined as the ratio of loading intensity failure in pressure (kN/m^2) of each unit cell (stone column and all configuration PFA column) with the untreated soil loading pressure such as shown in Equation (4). From the experimental results obtained, the loading failure of each samples in kilo newton (kN) have been converted in loading pressure (kN/m^2) by dividing with the size of area plate. Table 10.0 indicates that the values of loading pressure failure and bearing capacity improvement factor for each sample. below.

$$N_{ct} = N_c \times F_b \qquad \text{Equation (3)}$$

$$F_b = \frac{P_{fc}}{P_{fs}} \qquad \text{Equation (4)}$$

Where,

N_{ct} = Coefficient of bearing capacity treated soil

N_c = Coefficient of bearing capacity untreated soil

F_b = Bearing capacity improvement factor

P_{fc} = Loading pressure failure of treated soil

P_{fs} = Loading pressure failure of untreated soil

Table 10.0: Bearing capacity improvement factor (F_b)

Sample	Loading Pressure Failure, P_f (kN/m^2)	Bearing Capacity Improvement Factor (F_b)
Soft soil alone	24.616	1.00
Stone column	36.641	1.49
50%PFA column	48.383	1.97
70%PFA column	54.749	2.22
90%PFA column	41.734	1.70
55%PFA column	34.943	1.42
65%PFA column	39.895	1.62
95%PFA column	34.802	1.41

From Table 10.0, unit cell samples with 10% cement content was dominating the immense value of bearing capacity improvement factor. 70%PFA have the highest value 2.22 of bearing capacity improvement factor followed by 50%PFA as a second highest 1.97, and the third is 90%PFA about 1.70. For 5% cement content, only 65%PFA that give a better value of bearing capacity improvement factor than conventional stone column This occur due to lack of pozzolanic reaction at skin side of column 55%PFA and 95%PFA. Even though, 95%PFA content high amount of fly ash but calcium oxide from cement is not enough to promote more hydration process and sand amount to form a stronger soil matrix. Figure 4.9 shows the comparison for both value of settlement improvement ratio and bearing capacity improvement factor. All the soil treated with PFA SC shows the higher value on settlement improvement compare to the soil treated with conventional stone column. For bearing capacity improvement factor, only 55%PFA and 95%PFA show the slight reduce than stone column. This due to during the process of loading applied stone was act as vertical drains which allowing water from the surrounding soil go upward to the top surface through the column. Because of that process of consolidation soft soil was occurred and indirectly improve the bearing capacity of the treated soil.

CONCLUSION

Ten configurations of PFA mixture used as a material additive to create bonding on stone column material. In design configuration mixture, volume of voids (equal to water volume) was used to determine the amount of mixture needed The purpose of test to investigate the interface behavior of each configuration with the soft soil. From the result obtained, most of the samples have slight significant different between other about 3% to 8%. Sample of 60%pfa was found that have the highest interface shear strength with 45.85%. Result from the test was considered does not present the actual behavior of skin friction of the all samples.

These due to both material; soft soil and PFA stone column (PFA SC) tested through surface to surface in direct shear test. And no chemical reaction occurs during the test where only involve the mechanical surface roughness of each material. Consequence of that, result from unconfined compression test has used for selection of configuration to be tested on main experiment. From the result obtained, PFA SC samples with 10% cement have double of compressive strength than 5% cement content. 70%pfa was the highest compressive strength with 4.23 MPa and 95%pfa was the lowest with 1.603 MPa.

Six configurations have been selected for comparison study between untreated soil, treated soil using conventional stone column (CSC) and treated soil with PFA SC under plate load test; 50%pfa, 70%pfa, 90%pfa, 55%pfa, 65%pfa, 95%pfa. Soft soil bed was prepared with average shear strength 4.5 kPa. From the result obtained show that sample PFA SC with 70%pfa give the higher value of settlement improvement ratio and bearing capacity factor with 4.45 and 2.22 respectively. Meanwhile, sample column for 95%pfa indicates otherwise. Thus, all the sample of PFA SC show a better result than CSC on the settlement performance. However, bearing capacity of CSC was parallel with the PFA SC especially with 5% cement content. From the experimental result, a few findings have been carried out:-

1) Soil treated with PFA SC has produce a better result 2 to 4 times better than CSC on settlement performance. And bearing capacity of soil treated with PFA column can be improved with adequate design of filler material mixture compare to stone column.
2) PFA SC with high cement content increase the settlement performance and bearing capacity of treated soil.
3) Huge amount of PFA on mix design PFA SC does not aid the increment of settlement improvement ratio and bearing capacity performance.
4) Adequate amount of sand in design mix PFA could increase the stiffness of PFA SC and indirectly the settlement improvement ratio and bearing capacity of treated soil.

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