

Ultimate bearing capacity of peat treated with cement columns in physical model

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Abstract. Peat is classified as very soft and problematic soil due to its natural behaviour of high compressibility, low in shear strength and with high natural water content. Cement column method is commonly used to stabilise the soil by improving the engineering properties. This research aimed to study the unconfined compressive shear strength and the ultimate vertical bearing capacity of stabilized tropical peat of East Coast of Peninsular Malaysia. A group of cement columns were tested in a series of physical model testing. To study the strength behaviour of peat with or without the cement stabilization, physical models were prepared with different variables such as; the number of cement column, proportion of binders (Ordinary Portland Cement-OPC) and the pozzolanic materials (Palm Oil Fuel Ash-POFA). In this research, a total of 9 physical models testing of peat soil including one without the stabilized cement column were conducted. A group of 4 and 6 cement columns with 25 mm diameter and 200mm in length each was installed. Samples were cured for 28 days as soon as the mixing of cement columns completed. After curing, a series of axial loads were applied uniformly on the pre-fabricated steel plate footing from the top of the cement column in order to study the ultimate bearing capacity of the stabilised soil. The change in strength of the soil was evaluated using Unconfined Compressive Strength (UCS) test. Based on the results, the highest ultimate bearing capacity was recorded in Model 6 with 6 cement columns with area improvement ratio of 18.83 %. The sample with 300kg/m³ of OPC has the highest UCS value of 106.88kPa. Hence, the cement columns mixed with binder and pozzolanic improved the strength and the ultimate bearing capacity of the peat soil.

1. Introduction

In Malaysia, there is around 3 million hectares or approximately 8% of the land is covered with peats. In state of Sarawak alone there are some 1.66 million of peat covering the land [1,2]. Peat is considered as the extreme form of an organic soil where the organic content is higher than 75%. The extensive formation of peat soil layer is due to the rate of accumulation of plant's remains is higher and faster than the rate of decomposition. The type of peat also represents the accumulation of disintegrated plant remains which have been preserved under conditions of incomplete aeration and high water content. The formation of peats is more favourable when the area is waterlogged, with excess rainfall and low permeability ground, irrespective of latitude or altitude [1-3]. The peat soil is classified as problematic soil due to its natural properties of high compressibility, low shear strength and high natural water content. The high compressibility of peat soil will poses problem of secondary settlement and even tertiary settlement in long term due to continuous decomposition activity. It was found that peat has the potential to decompose and its decaying rate could be accelerated by controlling the influencing factors like oxygen supply, C:N ratio, pH value and temperature for optimum condition [2]. The ever high water content condition of peat makes it unsuitable for construction. The water content of peat normally varies from 500% to 2000% while for peat where the

water content are less than 500% are usually indicates that there are high mineral fractions within the peat sample [1]. According to Hwang [3], when dealing with organic and peat soil, few options are available to improve or strengthen the soil, the engineer or owner can choose either (1) to strengthen the foundation, (2) eliminate the problematic soil (cut & replace), (3) apply soil treatment or relocate the project to better ground. Several methods such as surface reinforcement, preloading, vertical drain, deep stabilization, piling and chemical stabilization had been introduced by previous researchers in order to improve organic soil and peat soil. Dry Deep Soil Mixing (DSM) or simply the Cement Column mixing is a common method for soft soil stabilization. This in-situ stabilization method involves the mixing of cementitious compound such as Ordinary Portland Cement (OPC) and lime with peat soil. In this research, the cement column using OPC and palm oil fuel ash (POFA) is used to stabilize the peat soil. Physical models are constructed to simulate the field condition of the peat soil. The bearing capacity of the footings and the strength of the stabilized peat using a group of 4 and 6 cement column are analysed.

2. Materials and Methods

2.1. Sampling and soil classifications

Both the disturbed and the undisturbed soil samples were collected from Pekan, Pahang, Malaysia at a depth of 0.5 to 1m from ground surface. The soil samples were preserved in air tight container to prevent any loss of moisture content. A list of laboratory tests such as moisture content, organic content, fiber content, pH value, specific gravity, liquid limit, plastic limit, and unconfined compressive strength test were conducted to determine the engineering properties of the soil.

Moreover, the field density test was conducted using balloon density method to determine the actual field unit weight of the soil. The peat soil has been classified using the field using the Von Post Scale and based on the results obtained from laboratory tests.



Figure 1. In-situ peat classification technique

2.2. Physical model test chamber

A series of small scale physical models have been constructed with a dimension of 335mm x 525mm in area and 300mm in depth. The model was made of 8mm Perspex plate. In this research, the model was set up to create the undrained field condition. A layer of canvas sheet was placed at the bottom of the chamber to prevent water from draining out. A layer of lubricating oil was smeared on the inner surface of the chamber in order to reduce the skin friction between the wall and the soil. The peat soil was mixed thoroughly to reach homogenous condition. The soil was placed into the chamber in 3 layers and each layer was compacted with 25 blows of free fall steel plate.



Figure 2. Physical model chamber

2.3. Model design and cement column installation

The PVC pipe with diameter of 25mm and 200mm in length was used in this research. A thin layer of silicone grease was applied along the inner and outer surface of the PVC pipe casing before the insertion to decrease the friction between the pipe and the soil. The PVC pipe was pushed into the soil at predetermined location and depth. The soil-filled pipe was removed slowly from the model to create a hole. The removed soil was mixed with the different dosage of OPC and POFA to form cement-soil column as shown in Table 1. Finally, the cement-soil column was placed in the holes to make a composite foundation. There is no compaction was done during the insertion process of the mixture. The procedures were repeated until the column was completed to design length. The stabilized soil specimens in the chamber were cured for 28 days prior to the loading phase.

Table 1. Test conditions and dosage of admixtures

Model	Number of Column (n)	α (%)	Dosage	
			OPC (kg/m ³)	POFA (kg/m ³)
1	-	-	-	-
2	4	12.27	300	0
3	4	12.27	250	50
4	4	12.27	200	100
5	4	12.27	150	150
6	6	18.38	300	0
7	6	18.38	250	50
8	6	18.38	200	100
9	6	18.38	150	150

α is defined as the area improvement ratio based on the cement column area and treatment area



Figure 3. Installation of cement columns using PVC tube

In this phase, a rigid square steel plate with dimension of 200mm x 80mm and thickness of 20mm was designed to represent a rigid body resting on the stabilized soil. A series of loadings as shown in Table

2 were applied on the footing continuously and the settlement of the footing was recorded by 2 dial gauge placed on opposite sites across the centre of the footing. All the cement columns in each physical model were extruded out for the UCS test in order to obtain the UCS value. The reading for stress and deformation were taken every 10 seconds.

Table 2. Applied loading on steel plate footing

Day	Mass of steel plate (kg)	Loading (kN)
1	2	1.23
2	4	2.45
3	8	4.91
4	16	9.81
5	32	19.62
6	64	39.24
7	100	61.31

3. Results and Discussions

3.1. Soil and admixtures properties

Von Post Scale was used for the classification of peat soil. This scale is based on the degree of humification, appearance of soil and colour of water dripping out when the soil is being squeezed. The peat was classified as H3 according to the system as it is slightly decomposed peat soil, which, when squeeze, release muddy brown water, but from which no peat passes between fingers. Plant remains still identifiable and no amorphous material present. The engineering properties of the soil are shown in Table 3. It can be seen that most of the values obtained were not in the range of the published data. According to researchers [4,5], the soil can only be classified as peat when the organic content is greater than 75% while for organic content between the range of 25-75% should be classified as organic soil. The chemical composition and properties of both admixtures have been analysed using X-Ray Fluorescence (XRF). The Table 4 showed the chemical composition for the OPC and POFA.

Table 3. Engineering properties of tropical peat soil

Properties	Results	Published Data	Reference
Water Content (%)	362.12	198-417	[5-9]
Organic Content (%)	33.24	41-99	[5-11]
Fiber Content (%)	30.54	31-77	[6-11]
Liquid Limit (%)	69.85	202.3-220.7	[7-11]
Specific Gravity	1.91	0.95-1.34	[7-11]
pH value	3.3	3-5	[5-11]
Dry Unit Weight (kN/m^3)	10.64	10-13	[5-11]

Table 4. Chemical composition of admixtures

Properties	OPC	POFA
Silicon Dioxide (SiO_2)	21.45%	42.21%
Calcium Oxide (CaO)	60.98%	9.60%
Potassium Oxide (K_2O)	0.51%	7.59%

Iron Oxide (Fe_2O_3)	3.50%	4.88%
Phosphorus Pentoxide (F_2O_5)	-	4.35%
Aluminium Oxide (Al_2O_3)	3.62%	3.74%
Magnesium Oxide (MgO)	0.59%	3.67%
Sulphur Trioxide (SO_3)	-	1.69%
Loss of Ignition (LOI)	1.37%	2.55%

It can be seen that most of the chemical values of POFA is close to the value of OPC. According ASTM standard [12], POFA used for this research can be classified as Class C in pozzolanic material which can be used to partially replace the OPC in soil improvement. The Silica or the Silicon Dioxide (SiO_2) in POFA will react with the residue from the hydration process of cement to produce secondary C-S-H gel. The secondary C-S-H gel will contribute to the strength of the cement column and increase the strength of the soil.

3.2. Physical model test results

The ultimate bearing capacity (UBC) of the improved soil is contributed by many factors. In this research, the factors of area improvement ratio and shear strength of the soil and column were studied. Figure 4 and figure 5 showing the relationship between vertical stress and settlement for model with 4 cement columns ($\alpha=12.27\%$) and 6 cement columns ($\alpha=18.38\%$). The footings with higher ultimate bearing capacity, Q_{ult} for both 4 and 6 cement columns models were compared with unstabilised peat. Model 8 showed the greatest improvement towards the ultimate bearing capacity of the footing as it has the stiffest line when compared to other models. Area improvement ratio is correlated to the number of cement columns used for the treatment zone. When the number of cement columns used increases, the area improvement ratio increased too. In this research, there are only 2 groups of cement columns being considered; 4 cement columns group and the 6 cement columns group. The area improvement ratio corresponding to models with 4 and 6 cement columns group were 12.27% and 18.38% respectively. Compared to the untreated soil, the percentage of increment in terms of ultimate bearing capacity using 4 cement columns group varied from 200-280%, meanwhile for 6 cement columns group, the percentage of increment varied from 300-780%. From the results obtained, it clearly shows that the area improvement ratio effect the stabilised peat soil in terms of the bearing capacity. The major benefit for this performance is when the area improvement ratio is high, the capacity to distribute load through the cement column are more efficient and extensive.

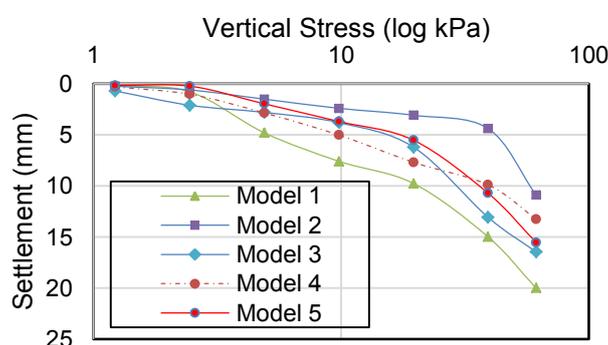


Figure 4. Relationship between vertical stress and settlement for $\alpha=12.27\%$

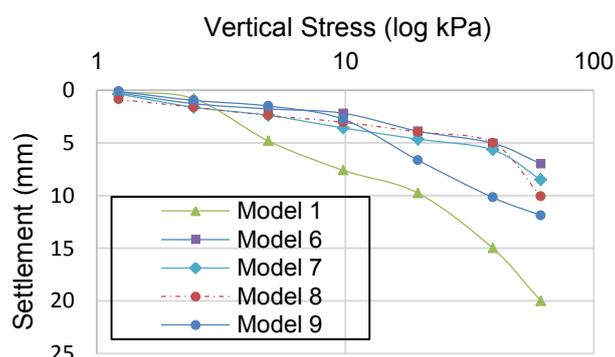


Figure 5. Relationship between vertical stress and settlement for $\alpha=18.38$

Figure 6 illustrates the stress and strain curve for the UCS test. From the results obtained, it shows that Model 4 (Peat + 200kg/m³ OPC + 100kg/m³ POFA) has the highest UCS value of 92.34kPa. Moreover, the UCS value obtained in Model 4 is greater than Model 2 (Peat + 300kg/m³ OPC). This clearly shows that the strength achieved in Model 4 is greater than Model 2. From the same figure, it was observed that the UCS value decreased when sample was mixed with the same amount of different type of binders such as in Model 5 (Peat + 150kg/m³ OPC + 150kg/m³ POFA). In all cases the best performance was achieved when the OPC used was two times the amount of POFA.

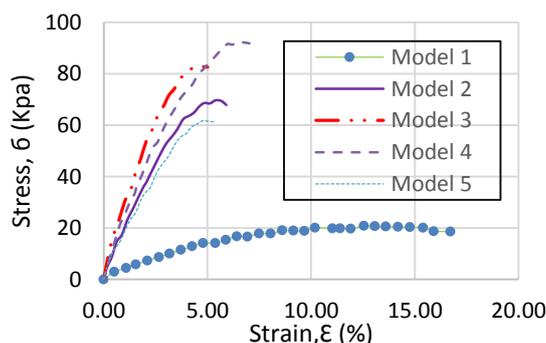


Figure 6. Stress and strain response during UCS test

4. Conclusion

The main objective of this research was to study the effectiveness of cement columns in increasing the shear strength and the ultimate vertical bearing capacity of footing on peat soil. This research proved that the location of where the peat soil is plays an important factor when it comes to choosing the right technique. Findings from this research confirmed that the combination OPC and POFA could serve as the most cost effective binder for the cement column in improving the ultimate bearing capacity and shear strength of the peat soil. The ultimate bearing capacity value for the stabilised peat soil treated with the 6 cement columns of 300 kg/m³ OPC was 39 kPa as compared to untreated soil which only had 5 kPa for the ultimate bearing capacity. This research proved that the ultimate bearing capacity of the soil effected by the area of improvement and the number of cement columns used for peat soil stabilisation. The ultimate bearing capacity of peat soil treated with 6 cement columns was higher as compared to the ultimate bearing capacity of peat soil treated with only 4 cement columns. This research proved that peat soil can be improved in terms of shear strength and bearing capacity using OPC with two times the amount of POFA as binders when mixing cement column.

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