Precast Peat Columns Stabilized with Cement and Fibers to Reinforce Peat Deposits

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Abstract

Peat and organic soil represent the extreme forms of soft soil, susceptible to localized sinking and massive and long-term settlement when subject to even moderate load increase. This article describes laboratory study on precast columns made of peat and cement, with and without polypropylene fibers. The process of making precast stabilized peat columns include mixing peat with a specified amount of cement, with or without polypropylene fibers, at their optimum moisture contents (OMC). The mixture is then compacted in the moulds and left to dry in the air. It was found that the OMC of the peat was quite high and it was believed that no extra water is needed for the complete hydration of cement to take place. When drying is complete, they are taken out of their molds and inserted in predrilled holes in undisturbed peat samples. The strength of the precast stabilized columns was evaluated by carrying out consolidated-undrained triaxial tests. The results obtained from shear strength analysis and stress-strain curves show that precast stabilized peat columns with or without polypropylene fibres can be used to reinforce weak deposits of peat with a substantial gain in the strength.

Key words: Peat, Polypropylene fibers, Precast columns, Stabilization

1. Introduction

Peat and organic soil represent the extreme forms of soft soil. They are susceptible to instability such as localized sinking and slip failure, and massive and long-term settlement when subject to even moderate load increase (Jarret, 1995). Access to these surficial deposits is usually very difficult as the water table will be at, near or above the ground surface with low shear strength ranging from 5 to 20 kPa (Huat, 2004). The modification of soil properties to improved states of load-bearing capacity may be done in a number of ways, such as, compaction, preloading, drainage, densification, grouting, chemical stabilization and by using geotextiles.

Sometimes it may be possible to combine different methods to provide a suitable foundation for the imposed loads. Hebib and Farrell (2003) provided a technique of surface stabilization combined with stabilized cement columns for foundation load support. Black et al. (2007) in their study used a reinforced stone column that not only transfers loads to the lower and stronger layer but receives lateral support from the weak soil along the way. Rahman et al. (2004) in their laboratory study increased the shear strength of undrained peat by almost 36% using drainage methods.

In this laboratory research, oven-dried 100 mm long precast stabilized columns made of peat, ordinary Portland cement, and polypropylene fibers have been inserted in undisturbed peat samples prepared for consolidated-undrained (CU) triaxial tests. Triaxial (consolidated-undrained) tests have been carried out on the undisturbed peat samples as control samples as well as on a combination of undisturbed peat samples having precast stabilized column made of different amount of cement with and without polypropylene fibers. The results indicate that installing precast stabilized peat columns in undisturbed peat improves substantially the shear strength of the peat.

2. TEST MATERIALS

2.1 Peat

Peat used in this study was collected as disturbed and undisturbed samples according to AASHTO T86-70 and ASTM D 42069 from Kampung, Jawa western part of Malaysia. Table 1 presents the properties of in-situ peat.

2.2 Ordinary Portland Cement

The stabilizing agent used for the columns was ordinary Portland cement (herein after called cement).

2.3 Polypropylene Fibers

Polypropylene fibers (Fig. 1) were used as additive to increase the strength values of the columns as well as increasing the column's intactness and uniformity (Kalantai and Huat, 2008). Table 2 presents the specifications of the fibers.

Figure 1 Photograph of polypropylene fibers

Table 1 Properties of Peat

Properties	**Values**
Depth of sampling	0.05-1.0 m
Moisture content	198-417%
Bulk unit weight (in-situ)	10.23-10.4 kN/m^3
Classification	Fibrous
Liquid limit	160%
Plastic index	Non-plastic
pH	6.81
Organic content	80.23%
Optimum moisture content	130%
Maximum dry unit weight	4.89 kN/m^3
Hydraulic conductivity	0.423 m/day
Initial void ratio	12.55
Compression index	4.163
Recompression index	0.307
Unconfined compressive strength	28.5 kPa

Table 2 Specifications of Polypropylene Fibers (SIKA, 2005)

Specifications	**Values**
Color	Natural
Specific gravity	9.1 kN/m^3
Length	12 mm
Diameter	18 μ (nominal)

Tensile strength	300-440 MPa
Elastic modulus	6000-9000 N/mm^2
Water absorption	None
Softening point	160 °C

3. EXPERIMENTAL PROGRAM

In order to examine the effect of precast stabilized peat columns on the shear strength parameters of peat, index property tests on the peat were conducted. The tests included: water content, liquid limit, plastic limit, organic content, fiber content, compaction, unconfined compressive strength, permeability, and Rowe consolidation cell. Consolidated-undrained triaxial tests were conducted on the undisturbed peat as well as on precast peat columns made of peat with different amounts of cement as well as peat with cement and optimum dosage of polypropylene fibers, as presented by Kalantari and Huat (2008). A mixture of peat, cement, and polypropylene fibers were used to make dried stabilized peat columns at their optimum moisture contents.

3.1 Dosage of Cement and Fibers for Precast Peat Columns

For investigating the effect of precast stabilized peat columns on the shear strength values of plain peat soil, a total of four different dosages of cement were chosen at 5, 15, 30, and 50% by weight of wet peat. Fibers used in this study had a constant value of 0.15% by weight of wet peat. The value of 0.15% was used by Kalantari and Huat (2008) for the stabilization of peat using cement and fibers. It was found to be the optimum dosage amount resulting in the maximum strength values in unconfined compressive strength and CBR tests.

3.2 Compaction Process

Modified compaction tests were performed to find the optimum moisture contents (W_{opt}) for the peat, and also for the mixture of peat with 5, 15, 30 and 50% of cement, as well as peat with the same amount of cement including 0.15% of fibers.

Prior to the compaction tests, the wet natural peat with water content of 198 to 417% (natural water content of peat soil) was dried to reduce its water content to approximately 50% by placing the natural peat in the oven at a temperature of 60 °C for more than five days. This gradual drying of natural peat samples procedure has been used instead of the usual method of complete drying of peat to prevent the possible change of soil texture. The samples for the test were prepared by mixing the specified amount of peat, cement and fibers in an electric dough mixture for ten minutes to achieve uniformity.

3.3 Preparing Peat Samples with Precast Stabilized Columns

Each set of columns, 16.67 mm in diameter and 100 mm long were prepared with peat at its OMC, specified amounts of cement and with or without fibers. The area ratio of the columns with respect to samples for triaxial tests (area of the column/ area of the peat soil sample) was

0.11 with a column c/c (center to center) spacing of 3.0 and a L/D (length to diameter) ratio of 6.0 (Alwi, 2008).

After preparing the mixture of stabilized peat, it was placed in non-reusable molds made of plastic sheet cover and tapes in a form of plastic tubes. Each sample of peat was placed in five layers, and each layer was given 56 blows with a metal rod weighing 384 grams for compacting it and was let to dry in oven. In order to prevent possible cracking in the samples owing to the high temperature of drying, the prepared column samples were placed inside an oven with a temperature of 75 °C for three days for gradual drying.

3.4 Preparation of Samples for Triaxial Tests

Undisturbed peat samples were placed inside the standard steel mold of triaxial tests with each sample with length and diameter dimensions of 100 mm and 50 mm respectively and covered with rubber membrane. Using a thin wall (0.25 mm) metal tube cutter of the same size as the column diameter (Fig. 2(a)) a hole was made at the center of the undisturbed peat soil. The precast stabilized peat column was then inserted in to the hole as depicted in Fig. 2(b). Finally, undisturbed peat samples along with the columns at their center were placed in the triaxial cell for consolidated-undrained tests.

(a) **(b)**

Figure 2 (a) Precast stabilized column and undisturbed peat sample, **(b)** column placed in the sample

3.5 Consolidated-Undrained Triaxial Tests

Consolidated-undrained (CU) triaxial tests were conducted on three types of samples. The first type included undisturbed peat samples. In the second and third types, the undisturbed peats were tested with precast stabilized columns at their center. For the second type of samples tested, the precast columns consisted of 5, 15, 30 and 50% of cement with peat, and for the third type of samples comprised 5, 15, 30 and 50% of cement along with 0.15% of fibers.

A computerized programs using GDSLAB v 2.2.7 software was used for the consolidated-undrained tests. For all the samples, the consolidation pressure of 50 kPa was used. Confining pressure used to shear the samples was, 50, 100 and 150 kPa respectively at a strain rate of 0.24% per minute. The total time taken for completing one test varied from 24 to 30 hours.

3.6 Soaking Columns Test and Results Obtained

In order to test the columns, at their weakest condition possible, that is when they were 100% saturated, tests have been conducted on columns made of peat, 50% cement and 0.15% fibers. Reason to choose columns with 50% cement and 0.15% fibers was, because this type of stabilized samples showed maximum strength values, and therefore it was chosen as control sample for soaking test.

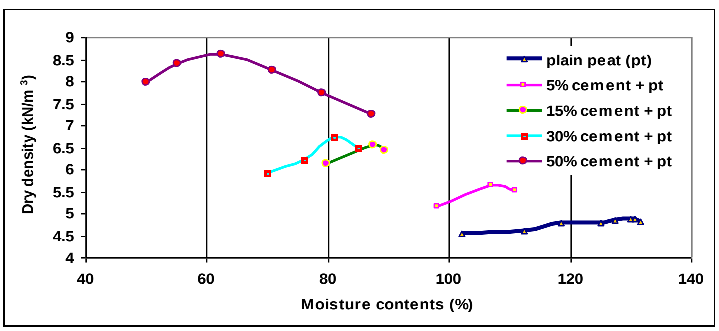
Procedure included submerging the precast stabilized peat column samples with the above mentioned specified amount of peat, cement and fibers in water for 4 days. The submerged samples were weighed every 24 hours for possible weight increases. It was observed that the samples reached their 98.9% of their constant weight or 100% of their saturation condition during the first 24 hours. Therefore, it was assumed that all samples containing 5, 15 and 30% cement were also 100% saturated at the end of 24 hours, before performing any test.

4. RESULTS AND DISCUSSIONS

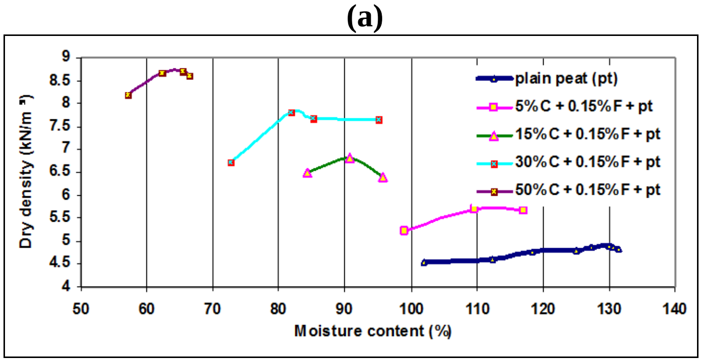
4.1 Compaction Tests

In order to find the moisture-density relation, modified compaction tests according to AASHTO T 180-D were conducted on plain peat soils as well as a mixture of peat and different amounts of ordinary Portland cement with and without polypropylene fibers. From moisture-density curves, optimum moisture content (OMC) was found for each set of peat soil mixtures.

Moisture-density relation curves for 5, 15, 30, and 50% cement mixed with peat soil, as well as 5, 15, 30, and 50% cement with peat soil plus 0.15% of polypropylene fibers, are shown in Figures 3(a) and (b) respectively. The compaction curve for the plain peat soil sample has also been presented as a control measure sample in both Figures.



(a)



(b)

Figure 3 Moisture-density relationship: **(a)** peat, and peat with different amounts of cement, **(b)** peat, and peat with different amounts of cement and 0.15% of fibers.

A comparison of results shown in Figure 3 shows that, as the cement content of the mixture is increased, the optimum moisture content (OMC) decreases, and dry density increases. As fiber contents are introduced to each set of peat mixture, the OMC decreases and dry density of the mix increases. The decrease in OMC and increase of dry density for the mixtures containing fibers are slight when compared with mixtures without fibers.

4.2 Consolidated Undrained Tests

In order to find the effect of precast stabilized columns on the undisturbed peat samples, consolidated-undrained (CU) triaxial tests were conducted on undisturbed peat, as well as with columns of peat and 5, 15, 30 and 50% cement. CU tests were also conducted for undisturbed peat samples with columns containing 5, 15, 30, and 50% cement and 0.15% fibers.

For each set of samples, the stress path method using p and q values were used to construct k_f line (Figure 4). From k_f line, and its equation, total shear strength parameters, cohesion (c_u) and friction angle (φ_u) for the consolidated undrained samples were calculated.

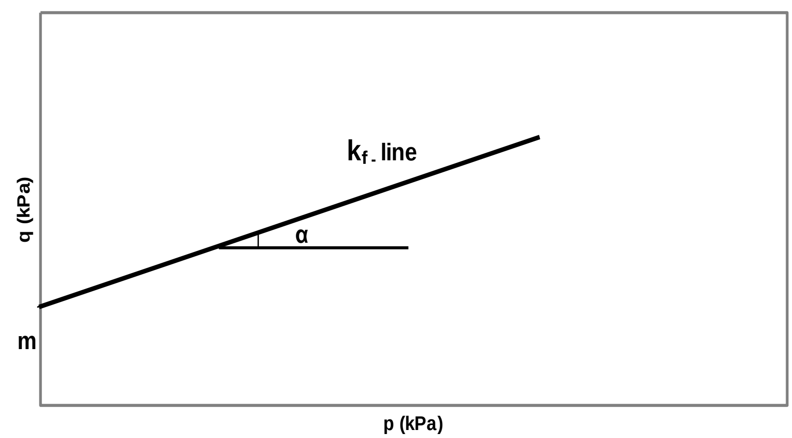


Figure 4 p-q diagram and k_f line for a triaxial test sample

After calculation of total shear strength parameters, the effective shear strength parameters (c'_u and φ'_u) for each set of samples were calculated in the same manner as described for total shear strength parameters, except, in this case, the k'_f line that is represented by was constructed instead of k_f line, taking the pore pressure (u) measurements at the time of failure of each sample into account.

Table 3 Shear Strength Parameter for Undisturbed Peat and for Peat with Different Types of Precast Stabilized Peat Columns

Specifications	c_u (kPa)	φ_u (degree)	c'_u (kPa)	φ'_u (degree)
Undisturbed peat	5.03	13.31	0.0	36.64
Peat + 5% cement	24.4	4.6	9.44	16.8
Peat + 15% cement	13.13	12.6	6.3	35.6
Peat + 30% cement	2.42	20.52	23.8	20.95
Peat + 50% cement	35.7	4.9	0.0	42.82
Peat + 5% cement + 0.15% fiber	9.43	16.8	16.85	19.63
Peat + 15% cement + 0.15% fiber	0.45	26.9	12.93	39.9
Peat + 30% cement + 0.15% fiber	25.8	16.97	26.0	27.92
Peat + 50% cement + 0.15% fiber	80.6	1.7	44.6	24.3

Results shown in Table 3 show that precast stabilized long peat columns (L/D > 4) made of different percentages of cement and peat improve the shear strength of plain undisturbed peat soil samples. As the cement content for the columns is increased, the shear strength values of the samples are improved as well. Addition of 0.15% of polypropylene fibers to the mixtures of peat and cement would add to the total as well as effective consolidated undrained shear strength parameter values further.

Figure 5 shows stress versus strain values for peat and different types of precast stabilized peat columns installed in the undisturbed peat. It is observed that the lowest maximum stress deviator is for the peat, and the highest is for the peat plus 50% cement and fiber, and values for maximum deviator stress for the other types of undisturbed peat soil with different types of columns fall between these two values. As the cement contents in the columns are increased the maximum deviator stress values for them are increased as well. The results in Figure 5 show that addition of 0.15% polypropylene fibers to the mixture of peat and cement in construction of precast columns provides more resistance against imposed loads.

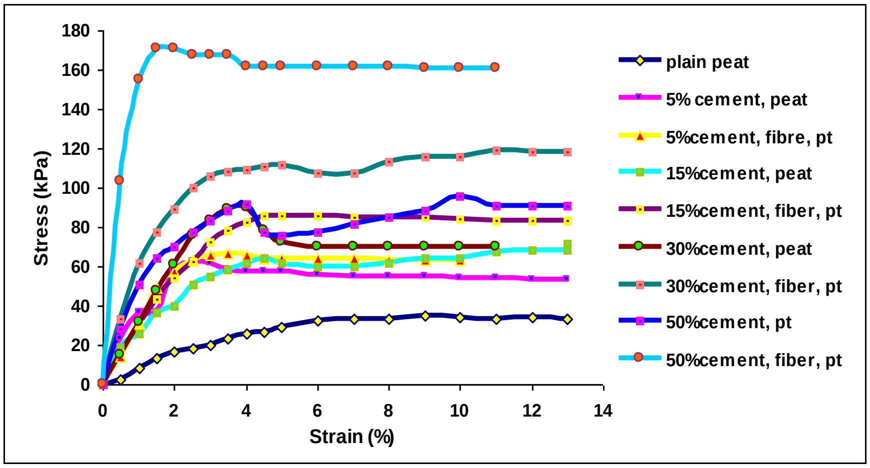


Figure 5 Stress-strain curves for undisturbed peat and different types of columns used to strengthen peat soil samples obtained from CU tests.

In order to study the strength values between the different types of precast stabilized peat columns used to strengthen undisturbed peat soil, undrained modulus (E_u) values were found from the initial tangent line of stress-strain curves shown in Figure 5.

The results indicated that dried stabilized peat columns do increase the undrained modulus of the peat. Also, as the cement content in the mixture of peat and ordinary Portland cement is increased, the value for E_u is increased, too. Addition of polypropylene fibers to the mixture increases the undrained modulus of the samples even further. The effect of polypropylene fibers is more profound in columns containing higher amounts of ordinary Portland cement (30 and 50%).

5. Conclusions

Peat soil is one the softest soils and is unable to resist construction loads imposed upon it. Different methods have been proposed to stabilize or strengthen peat soil deposits. One of the common methods presented in the literature to strengthen peat soil deposit, is to use in situ or in place columns (columns made inside the ground and in the peat soil layers on the field). These types of columns are usually made of 100% cement (cement columns) but, to lessen the amount of cement, some kind of filler material such as sand and in situ peat soils has also been used to strengthen the peat columns.

In this research a new type of column is introduced. It is made of a mixture of in situ peat soil (peat from the drilled hole), ordinary Portland cement, with or without additives (in this study polypropylene fibers were used as an additive). The mixtures are mixed at their optimum moisture content and are compacted in a mold outside the drilled holes (unlike the in situ (in place) columns that are formed inside the drilled hole), dried and finally the dried precast columns are inserted in the drilled holes inside the ground on the field.

In this laboratory-scale research, precast stabilized peat columns were tested for their strength effects on the undisturbed peat soil samples. The strength test that was conducted for this purpose was the consolidated undrained triaxial test. Various amounts of ordinary Portland cement along with polypropylene fibers were used to stabilize the precast peat columns.

The results obtained from shear strength parameters, stress-strain curves, and undrained modulus values show that precast stabilized peat columns used in the study are effective to improve load-bearing capacity of undisturbed peat soil. As the cement content in the mixtures is increased the strength values for the columns are increased as well. Polypropylene fibers when used in the mixtures of peat soil and ordinary Portland cement columns contribute more strength and uniformity to the stabilized columns.

Precast stabilized peat columns are environmentally friendly products too, since most of their ingredients come from the natural peat soils that are drilled out of the ground to form holes for the columns, and therefore do not produce much waste material; nor do they need extra fill materials (such as sand) except ordinary Portland cement and the usual additives (in this study, polypropylene was used as an additive).

The concept of precast stabilized peat columns can be used to produce short stabilized peat columns (L/D< 4) as well as precast stabilized piles to reinforce deep peat deposits, since they are more suitable for carrying larger loads than the long precast stabilized peat columns used in this research.

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