Scientific Research and Essays Vol. 6 (1), pp. 196-204, 4 January, 2011
Available online at http://www.academicjournals.org/SRE
DOI: 10.5897/SRE10.790
ISSN 1992-2248 ©2011 Academic Journals

Full Length Research Paper

A study of the compressibility behavior of peat stabilized by DMM: Lab Model and FE analysis

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Accepted 9 November, 2010

Peats are considered as extremely soft, unconsolidated deposits. These soils are geotechnically problematic, due to their high compressibility and low shear strength. Cement is widely used for the stabilization of peat by deep mixing method (DMM). This paper presents the results of the model study of compressibility properties of fibrous, hemic and sapric peats, stabilized with columns formed by DMM. The columns were formed of peat, treated with cement in different proportions. Rowe cell tests were performed after curing the samples for 28 days, to evaluate the compressibility characteristics. The results showed that the compressibility properties of peat can be improved significantly by the installation of cement stabilized columns. The amount of cement used to form the column and its diameter were observed to influence the engineering behavior of peats. The effect of cement was the highest on sapric peat among all, due to its physico-chemical properties. The results of Rowe cell were used to simulate the consolidation behavior using finite element software, PLAXIS and the results agree well. The parameters from the simulated model behavior were used to predict the ultimate bearing capacity of peat with full size cement stabilized columns.

Key words: Peat, cement column, compressibility, finite element analysis, bearing capacity.

INTRODUCTION

Peat deposits are found in many geologic and geographic settings throughout the world and constitute 5 to 8% of the earth's land surface. Two-thirds of the world coverage of tropical peat is in South East Asia. In Malaysia, about 30,000 km^2 of land area is covered with peat; which represents about 8% of the country's total land area (Huat, 2004; Mesri and Ajlouni, 2007). In recent decades, concern about organic soils and peat and its difficulties from the geoenvironmental and geotechnical points of view, have led to the development of many new techniques for improving them.

Peat largely consists of organic residues (more than 75%) accumulated from the partial decomposition of the remains of a variety of plants in certain types of ecosystems in which water is abundant (Moore, 1989). It has been classified to 10 degrees of humification (H1-H10) by von Post (1922), based on the degree of humification, botanical composition, water content and the content of fine and coarse fibers. According to the American Society for Testing of Materials (ASTM, 1992), the standard peat classification has been narrowed to three classes: (i) Fibric (fibrous; least decomposed with fiber content of more than 67%), (ii) Hemic (semi-fibrous; intermediate decomposed) and (iii) Sapric (amorphous; highly decomposed with fiber content of less than 33%).

Fibrous peat is peat with high organic and fiber content, low degree of humification (undecomposed fibrous organic materials), easily identifiable and extremely acidic. Sapric peat is the most decomposed peat material (original plant fibers have mostly disappeared), very dark gray to black in color and quite stable in physical properties, with water-holding capacity less than that of either fibrous or hemic peats. As compared with fibrous peat deposits, the sapric peat deposits are likely to exist at lower void ratios and display lower permeability anisotropy, lower compressibility, lower friction angle, higher coefficient of earth pressure at rest and high cation exchange capacity (CEC) (Weber, 1969; Edil and Wang,

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Table 1. Physico-chemical characteristics of untreated peats.

Parameter	Method	Fibrous	Hemic	Sapric
Moisture content (%)	BS 1377: Part 2: 1990, Clause 3	506.5	324.6	188.2
Specific gravity	BS 1377: Part 2: 1990, Clause 8.4	1.26	1.302	1.42
Organic content (%)	BS 1377: Part 3: 1990, Clause 4	94.23	81.3	75.31
Fiber content (%)	ASTM D 1997-91	79.1	53.2	31.3
Bulk unit weight (kN/m^3)	BS 1377: Part 2: 1990, Clause 7	9.86	10.3	11.1
pH	BS 1377: Part 3: 1990, Clause 9	3.8	4.81	5.97
Degree of humification (%)	von Post (1922)	H_3	H_6	H_9
Cation exchange capacity, CEC (meq/100g)	Gillman and Sumpter (1986)	63	71	86
Surface area (m^2/g)	BET technique (Brunauer et al., 1938)	56	73	96

2000; Huat, 2004; Asadi et al., 2009). The behavior of hemic peat, in terms of compressibility, shear strength and permeability can be said to be intermediate between fibrous and sapric peats.

Deep mixing method is the widely used method for stabilizing organic soils. This method, originally developed in Sweden and Japan more than thirty years ago, is becoming well established in an increasing number of countries. Åhnberg et al. (1995) reported that originally, lime was the only binder used, but cement has been widely used since the mid 1980s, with considerably higher strength achieved. The introduction of cement has made it possible to stabilize "problematic soils" with high organic contents and high water:soil ratios (Åhnberg, 2006; Janz and Johansson, 2002). Comprehensive trials and field works have been carried out where cement with different industrial binders have been shown to improve the mechanical properties (shear strength and compressibility) of organic soils and peats (Axelsson et al., 2002; EuroSoilStab, 2002; Hebib and Farrell, 2003).

The cementation and pozzolanic reactions have been investigated in detail by Kezdi (1979), Bergado et al. (1996) and Hwan Lee and Lee (2002). The factors affecting stabilized organic soil such as peat depend upon: the water content, physical, chemical and mineralogical properties; nature and amount of organic content and the pH of pore water. It has been reported by Tremblay et al. (2002) that, the properties of cement treated organic soils depend not only on the content of the organic matter but also on the nature or the type of the organic matter. Since, peat already has a high water content, the required water for soil-cement reaction comes from it. Therefore, Dry Mixing Method (DMM) and Dry Jet Mixing (DJM) methods are effective for peat stabilization instead of wet mixing method (Yang et al., 1998). Berry (1983) reported that the consolidation process of peat is complicated by the occurrence of secondary compression, which appears to extend indefinitely. Further, the rapid changes in permeability and the large strain have a significant influence on the consolidation behavior of peat. Berry and Poskitt (1972) suggested that, since the composition of natural peat deposits may vary considerably among different sites, as do their mechanical properties, the analysis becomes very site specific.

An attempt has also been made to model the consolidation behavior of peat, using finite element software, PLAXIS (PLAXIS BV, The Netherlands). Modeling the consolidation behavior of peat by Karunawardena and Kulathilaka (2003) was not very successful, and it was concluded that the extreme variation in the coefficient of consolidation with the applied pressure, has been observed primarily due to the very large changes in the coefficient of permeability and a reduction of void ratio, during the consolidation process. A similar finding was also reported by MacFarlane (1969).

In this paper, an attempt has been made to evaluate the effects of DMM method, using cement on the compressibility columns in peats. This model study was initiated in order to evaluate the influence of dry cement to stabilize peats, in terms of a reduction in compressibility, by performing Rowe cell tests. Finally, the results from Rowe cell test have been used to predict the ultimate bearing capacity of peat with full size cement stabilized columns using PLAXIS.

MATERIALS AND METHODS

Materials

Peat was collected from various locations near Kuala Lumpur, Malaysia, to have all the three varieties: fibrous, hemic and sapric peats. The physico-chemical properties of fibrous, hemic and sapric peats are presented in Table 1. Ordinary Portland cement (hereinafter called cement), used in this study as a binding agent, was obtained locally. The chemical composition of the cement, as provided by the manufacturer, is summarized in Table 2.

Methodology

Sample preparation

A suitable auger (sampling tube and containers) was designed and

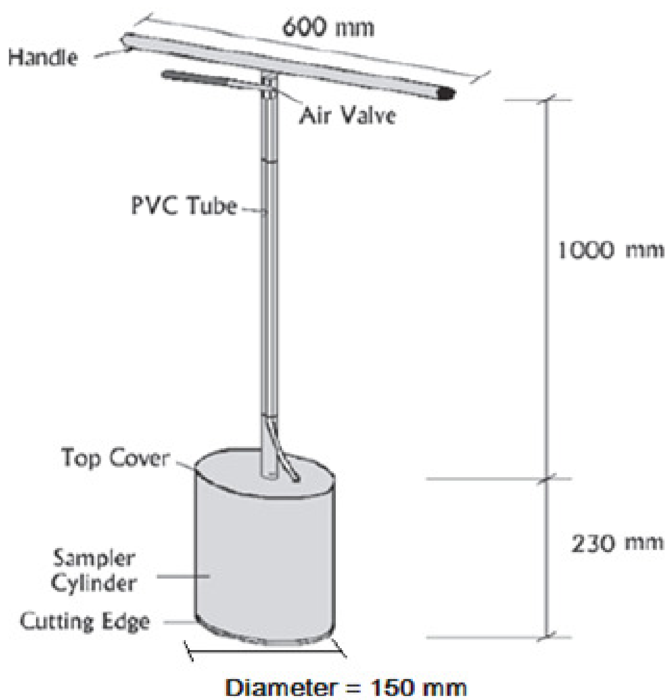

Figure 1. Schematic diagram of peat sample. (Kazemian et al., 2009a).

Table 2. Chemical composition of cement.

Constituent	(%)	Constituent	(%)
SiO_2	21.0	MgO	1.1
Al_2O_3	5.3	SO_3	2.7
Fe_2O_3	3.3	Na_2O	1.0
CaO	65.6	Loss of ignition	0.9

fabricated (Figure 1) to collect undisturbed peat samples. Reference is made to BS 1377-1 (1990) for the sampler preparation method. It consists of a thin hollow cylindrical tube 150 mm in diameter (internal) and 230 mm high. The upper part of the cylindrical hollow body is fitted with a cover plate. The lower part of the cylindrical tube has a sharp edge to cut roots as the auger is slowly rotated and pushed into the peat ground during sampling. The height of the cutting edge was 10 mm. The thin tube is fitted with a valve which is left open during sampling to release both air and water pressure. The valve was then closed, prior to withdrawal of the tube with the peat sample enclosed, thus providing a vacuum effect to help the sample in place. The handle was formed of a 600 mm cross bar and the stem was 1000 mm in height and 50 mm in diameter. Soon after the sampler was withdrawn, the cylindrical tube was sealed with paraffin wax to retain the natural moisture in Once in the laboratory, the top cover on the cylindrical tube was opened to extract the sample. The auger enables the extraction of samples 150 mm in diameter and 230 mm in height. The top and bottom of the specimen was trimmed carefully and quickly to minimize any change in the water content of the soil sample (Figure 2 (a)). According to BS 1377-8 (1990) and BS 1377-6 (1990), the height (H) of the specimen was 37.5 mm for the consolidation test. In order to evaluate the of peat reinforced by stabilized cement

Table 3. Various quantities of cement used in cement stabilized columns.

Specification	Sample
Untreated peat	**Control sample**
Peat = 50%; Cement = 50%	Sample I
Peat = 30%; Cement = 70%	Sample II
Peat = 20%; Cement = 80%	Sample III
Peat = 10%; Cement = 90%	Sample IV

column, samples of peat with cement column were prepared by inserting a PVC tube in the center of the specimen and extracting soil from within the tube. Next, the extracted peat, at its natural water content, was thoroughly homogenized by household mixer the sample (Kazemian et al., 2009a) and then cement was added to it, at a typical dose rate of 200 kg/m^3, according to the findings of Axelsson et al., (2002). The stabilized cement columns in the composite peat samples were prepared with cement:peat ratio of 50:50, 70:30, 80:20 and 90:10 (Table 3). The cement-peat mixture was thoroughly mixed for five minutes and then replaced back in PVC tube and compacted properly. The tube was finally withdrawn forming the stabilized cement column (Figure 2 (b)). Care was taken to replace back the peat-cement mixture as soon as possible, but not later than 30 min; as this was the initial setting time of cement. The columns formed in peat were of diameters (R) either 27.5 mm (column-area ratio = 13.45%) or 37.5 mm (column-area ratio = 25%). The samples were then cured for 28 days in a soaking basin, before performing consolidation tests (Rowe cell).

Hashim and Islam (2008) and Holm (1999; 2000), presented several case histories of deep mixing in a variety of conditions and the typical column-area ratios (cement column area to treated peat area) being used in practice are between 5 to 35%. In this study, the cement column diameters were 27.5 mm and 37.5 mm and the column-area ratio were 13.45% and 25% respectively.

Experimental methods

Physical properties of peat and treated peat columns with different cement ratio were determined and the parameters evaluated are; organic content, water content and specific gravity in accordance with BS 1377-3-4 (1990), BS 1377-2-3 (1990) and BS 1377-2-8.4 (1990), respectively. The bulk unit weight, pH and fiber content of the specimens were determined according to BS 1377-2-7 (1990), BS 1377-3-9 (1990) and ASTM 1997-91. Further, the CEC and surface area were determined based on Gillman and Sumpter (1986) method and the BET technique (Brunauer et al., 1938), respectively.

To overcome most of the disadvantages of the conventional oedometer apparatus, Rowe cell has been used. The important features of Rowe cell are its ability to control drainage and to measure pore water pressure during the course of consolidation and to overcome the disadvantage of the oedometer apparatus, when performing consolidation tests on low permeability soils, including non-uniform deposits. The consolidation tests on peat were performed based on BS 1377-6 (1990). The compressibility characteristics of peats determined are: (i) Compression index (C_c) and (ii) Coefficient of secondary compression (C_α).

Finite element analysis

The results obtained from the Rowe cell test were used to simulate the consolidation behavior of peat. The parametric study was

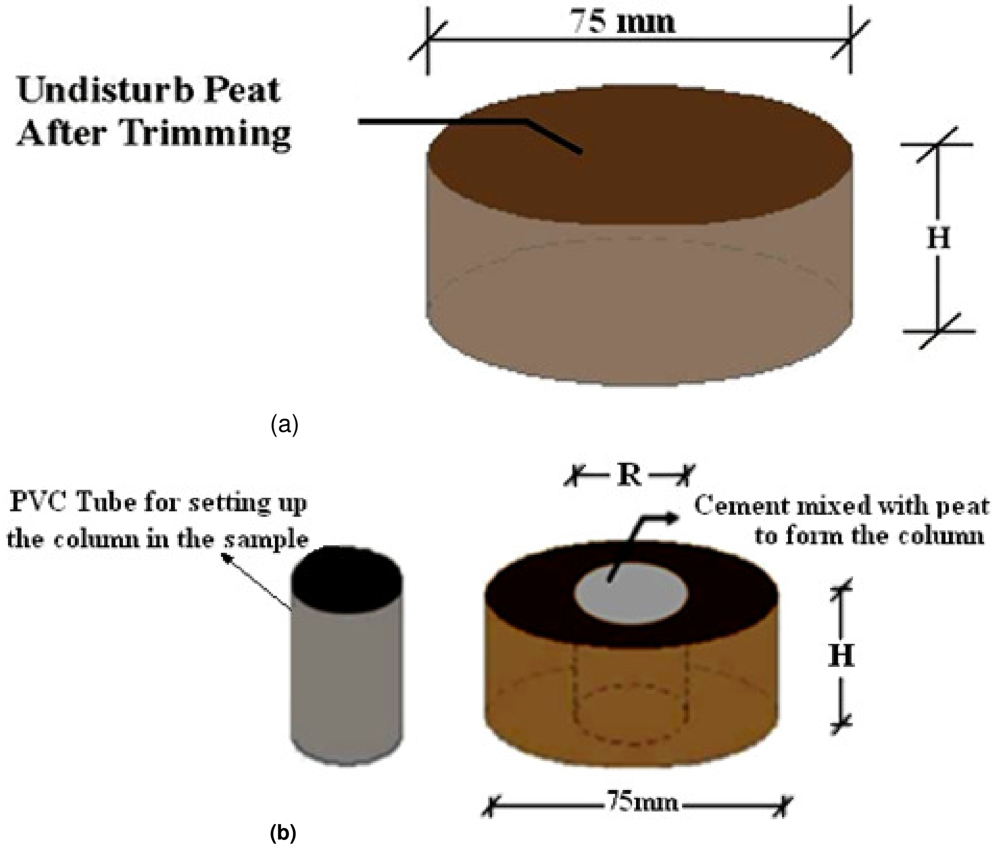

Figure 2. Sample preparation (a) cylindrical test specimen from the undisturbed soil sample after trimming and (b) method used to set up cement column in specimen.

Table 4. Parameters for finite element analysis.

Parameter	Value
Material model	Soft soil creep
Type of behavior	Drained
Soil unit weight (γ)	11.0 kN/m^3
Poisson's ratio (v)	0.35
Cohesion (*c*)	1.0 kN/m^2
Friction angle (*φ*)	20°
Dilatancy angle (*ψ*)	0°
Modified swelling index (*κ**)	0.022
Modified compression index (*λ**)	0.12
Modified creep index (*μ**)	0.006

carried out using finite element software, PLAXIS. The parameters used in the analysis were adopted from the results of Rowe cell test carried out on fibrous, hemic and sapric peats and are presented in Table 4. An axisymmetric analysis was carried out, using the soft soil creep model. The parameters required for the analysis are unit weight (γ), Poisson ratio (v), cohesion (c), friction angle (φ) and dilatancy angle (ψ). In addition, the basic stiffness parameters required are modified swelling index (κ*), modified compression index (λ*) and modified creep index (μ*). A drained behavior is assumed for the materials, as peat has a very high permeability. This behavior is also justified for the fact that, it was assumed that sufficient time had lapsed, after the application of the load and the stress concentrations and the settlement had stabilized. The initial vertical stress due to gravity load has also been considered in the present analysis.

Drainage is permitted from the top as in Row cell test. A typical finite element mesh consisted of 2001 nodes and 240 fifteen-node triangular elements. Radial deformation is restricted along the periphery of the tank but settlement is allowed and along the bottom of the tank, both radial deformation and settlement are restricted. No interface elements have been used at the interface between the stabilized cement column and peat, as no significant shear is possible (Mitchell and Huber, 1985). To account for this, the elements immediately adjacent to the cement column are given lower shear strength values, equal to two-third of the strength of peat. This will allow the relative deformation between the column and adjacent peat. Saha et al. (2000) had also carried out a similar finite-element analysis of a column without an interface element. To simulate Rowe cell test condition, a four stage modeling was performed increasing the applied load in each stage. The loads applied to the samples are 50, 100, 200 and 300 kPa. Each load in a stage was maintained for one day and then the next load was applied.

The parameters obtained from the analyses of the results obtained from Row cell test were used to simulate the load carrying capacity of peat with full size cement stabilized columns. The analysis has been carried out for columns 1.0 m in diameter and

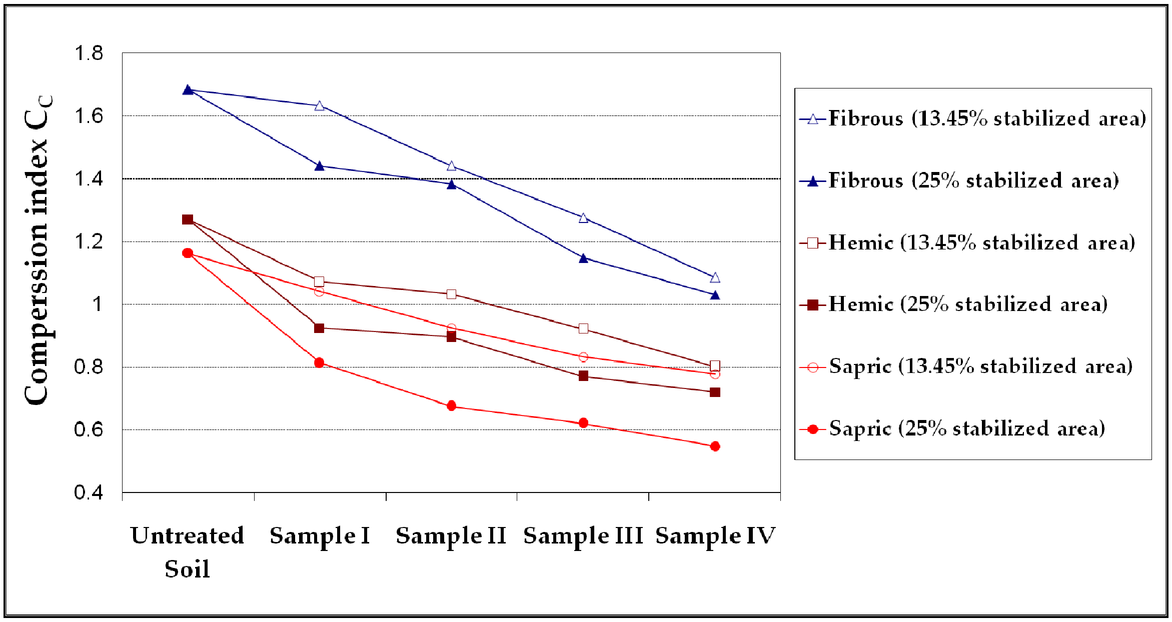

Figure 3. Compression index of treated fibrous, hemic and sapric peats for 50 kPa consolidation pressure.

5.0 m long, arranged in a triangular pattern. The length of columns was restricted to 5.0 m, since it represents the normal depth of peat deposit in Malaysia. The spacing between the columns were kept as 3 d (d is the diameter of column). The spacing of 3 d was chosen as it has been reported that this spacing gives the highest increases in the bearing capacity (Ambily and Gandhi, 2007; Murugesan and Rajagopal, 2007). A method to estimate the settlement of foundation resting on the infinite grid of columns based on unit cell concept was proposed by Priebe (1995). In this concept, the soil around a column for area represented by a single column, depending on column spacing, is considered for the analysis. As all the columns in such analyses are simultaneously loaded, it is assumed that lateral deformations in soil at the boundary of unit cell are zero. The behavior of all column soil units is the same except near the edges of the loaded area and thus only one column soil unit needs to be analyzed (Goughnour, 1983; Ambily and Gandhi, 2007).

The columns are usually installed in a triangular plan patterns in the field and for design and analysis purposes, a cylindrical unit cell is considered, consisting of column and soil from the influence area. The concept of composite cell model has been considered by many researchers for investigating several aspects of reinforced soils by columns, such as, increase of bearing capacity, prediction of settlement, reduction of soil consolidation (Bouassida et al., 2003; Guetif et al., 2003). The influence areas for columns installed in square and triangular plan patterns were calculated from that of an equivalent hexagonal area. Barron (1948) has suggested a method to calculate the radius of the circular influence area, as 0.525 s for triangular pattern where, ‘s’ is the center to center spacing between the columns. The cylindrical unit cell was idealized in the finite element model, using axisymmetric model with the radial symmetry around the vertical axis passing through the centre of the column.

For the simulation of the ultimate bearing capacity of peat with full size cement stabilized columns, the typical model consisted of 8589 nodes and 1050 fifteen-noded triangular elements. The external loading was applied in the form of displacement, equal to 20% of the column diameter. Iterative procedure was adopted for the solution to reduce the normal out of balance force, for the simulation of prototype column behavior.

RESULTS

Compressibility characteristics of cement columns stabilized peat

The compressibility characteristics of peats with cement stabilized column were studied by Rowe cell for pressures of 50, 100, 200 and 300 kPa. The compression index (C_c) of fibrous, hemic and sapric peats for pressure of 50 kPa is shown in Figure 3. As expected, the C_c of peats decreased with an increase in the cement content. The C_c of untreated fibrous peat with a column-area ratio of 13.45% was 1.69 and it decreased to 1.12 with 90% cement. Similarly, the C_c of untreated hemic and sapric peats with a column area ratio of 13.45%, were lower at 1.28 and 1.17, respectively and they decreased to 0.81 and 0.79, respectively. Further, with an increase in column-area ratio from 13.45 to 25%, the compression indices of fibrous, hemic and sapric peats decreased to 1.04, 0.74 and 0.56, respectively with 90% cement content. The nature of curves of C_c of fibrous, hemic and sapric peats, for consolidation pressures of 100, 200 and 300 kPa, were similar to those for 50 kPa.

The secondary compression index (C_α) of different peat samples was evaluated and is presented in Figure 4, for a consolidation pressure of 50 kPa. It was observed that C_α decreases with an increase in cement content for all peats; fibrous, hemic and sapric. The C_α of untreated fibrous peat with a column area ratio of 13.45% was 0.073 and as expected, it decreased to 0.045 with 90% cement. Similarly, the C_α of untreated hemic and sapric peats were 0.069 and 0.065 respectively, which is lower than that of fibrous peat. They decreased to 0.039 and

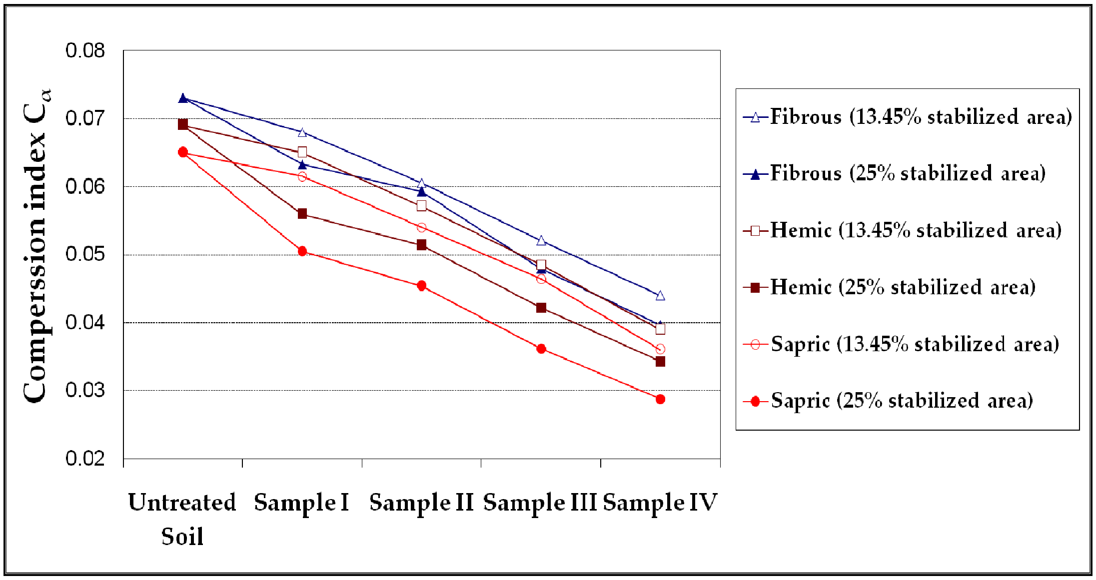

Figure 4. Secondary compression index of treated fibrous, hemic and sapric peats for 50 kPa consolidation pressure.

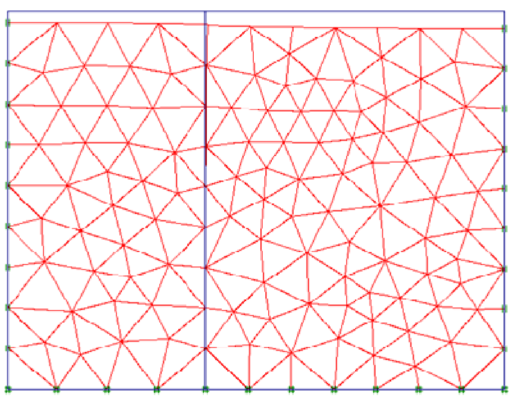

Figure 5. Deformed mesh of peat, and cement stabilized column as in Rowe cell (Only right half of model is shown, as it is axisymmetric).

0.036 for hemic and sapric peat respectively with 90% cement. Similarly, when the column-area ratio was increased to 25%, the C_α of fibrous, hemic and sapric peats decreased to 0.04, 0.035 and 0.029 respectively. The C_α of fibrous, hemic and sapric peats for a pressure of 50 kPa, was observed to be very high. The nature of curves of C_α of fibrous, hemic and sapric peats, at consolidation pressures of 100, 200 and 300 kPa, were observed to be similar to those at 50 kPa. The compressibility of peats stabilized with cement treated columns decreased with an increasing cement amount.

Finite element analysis

The Rowe cell tests on untreated and treated peat samples were simulated using finite element software PLAXIS. Figure 5 shows the typical results of deformed mesh, total displacement and effective stresses of fibrous peat with cement stabilized column. The displacement of 4.69 mm is very close to the actual recorded displacement of 4.76 mm at 50 kPa and with 10% cement. Similarly, very close agreements were observed between the actual values and the results obtained from PLAXIS for all the cases.

The parameters from Rowe cell test were used to predict the ultimate bearing capacity of full size cement stabilized columns formed in peat. The stabilized cement columns used in the present simulation were 1.0 m in diameter and 5.0 m long. It was assumed that the columns were resting on a firm soil bed. Unit cell concept (Ambily and Gandhi, 2007) was adopted and hence, only one column with its influence zone was used to simulate the behavior of a group of columns arranged in a triangular pattern at a column spacing of 3 d (d is diameter) and loaded simultaneously. The load was applied in the form of a prescribed displacement of 200 mm, which is equal to 20% of the column diameter for all the cases. The plots of deformed mesh, total displacement and effective stresses for column with 50% cement are presented in Figure 6.

The load at this displacement of 200 mm (20% column diameter) is taken as the ultimate bearing capacity of the cement treated column in peat and the results are presented in Figure 7. The ultimate bearing capacity for all the cases increased with an increase in the cement content. The load at failure of sapric peat was observed to be higher than that of hemic and fibrous peats. The ultimate load at failure of untreated fibrous peat was 44.17 kN and it increased to 78.04 kN for column with

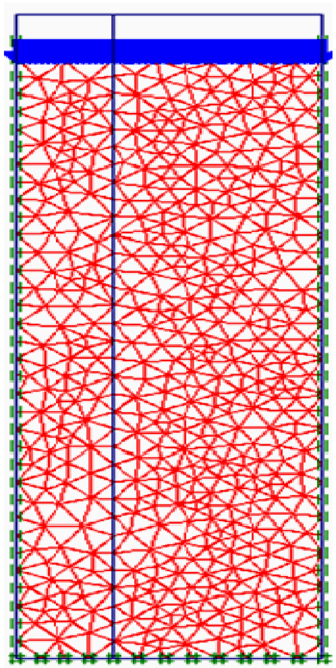

Figure 6. Deformed mesh of peat, and full size cement stabilized column.(Only right half of model is shown, as it is axisymmetric).

50% cement. Similarly, the loads at failure for untreated hemic and sapric peats were 49.63 and 51.33 kN respectively and increased to 84.83 and 96.14 kN for hemic and sapric peats respectively with 50% cement.

DISCUSSION

Compressibility characteristics of cement columns stabilized peat

As mentioned earlier, the compressibility characteristics of peats with cement stabilized column were studied by Rowe cell, for pressures of 50, 100, 200 and 300 kPa. As expected, the C_c of peats decreased with an increase in the cement content (Figure 3). The nature of curves of C_c of fibrous, hemic and sapric peats for consolidation pressures of 100, 200 and 300 kPa were similar to those for 50 kPa. This is due to the fact that, the cement particles bind together the soil particles, causing a decrease in compressibility. Fibrous peat shows a higher reduction in C_c compared with hemic and sapric peats. The reasons for this behavior are higher void ratio and the nature of fibers in fibrous peat, that allow for higher compression and bending. The secondary compression index (C_α) of different peat samples was evaluated and is presented in Figure 4, for a consolidation pressure of 50 kPa. It was observed that C_α decreases with an increase in cement content for all peats; fibrous, hemic and sapric.

When the column-area ratio was increased to 25%, the C_α of fibrous, hemic and sapric peats also decreased. The C_α of fibrous, hemic and sapric peats for a pressure of 50 kPa was observed to be very high. However, it agrees well with the findings of Mesri and Castro (1987) and Mesri et al. 1997 and Kazemian and Huat (2009). The nature of curves of C_α of fibrous, hemic and sapric peats, at consolidation pressures of 100, 200 and 300 kPa, were observed to be similar to those at 50 kPa. The compressibility of peats stabilized with cement treated columns, decreased with an increasing cement amount. This is quite obvious as the mass of binder is increasing per unit volume of the peat; cement increases the strength and transforms peat into a stiffer state as mentioned earlier. The effect of cement on compressibility parameters of sapric peat was higher among other peats, as stated above as well.

Secondary compression is completely explained and predicted by the law of compressibility, that is, C_α/C_c. The values of C_α/C_c of peat deposits are usually in the range of 0.06 ± 0.01 and it depends on the compressibility and deformability of peats (Hebib and Farrell, 2003; Mesri, 1987; Mesri and Castro, 1987; Mesri et al., 1997). The C_α/C_c was observed not to agree with the published results of 0.06 ± 0.01 (Mesri, 1987; Mesri and Castro, 1987; Mesri et al., 1997; Hebib and Farrell, 2003). This can be due to the presence of high organic matter. However, it agrees with the findings by some researchers (Lea and Browner, 1963; Fox et al., 1992; Paikowsky et al., 2003; Kazemian et al., 2009b) that C_α/C_c is not constant, but varies with the consolidation pressure.

The aforementioned findings are justified for the fact that when water comes in contact with cement, three reactions take place: (i) cement reacting with water called hydration, (ii) pozzolanic reactions between calcium hydroxide $[Ca(OH)_2]$ from cement and pozzolanic minerals in the soil and (iii) ion exchange between calcium ions (from cement) with ions present in the colloids of peats, which leads to an improvement in the strength of the treated soil. Cement initiates chemical reaction with water (called hydration) and tricalcium silicate (C_3S, in cement chemist notation) and dicalcium silicate (C_2S) (from cement) are mixed with water, calcium ions are quickly released into the solution with the formation of hydroxide ions. When the concentration of calcium and hydroxide ions reaches a certain threshold value, calcium hydroxide crystallizes out of solution and finally leads to the production of calcium silicate hydrate (C-S-H) and thus, bonding the particles and decreasing compressibility parameters or increasing the shear strength (Janz and Johansson, 2002; Kazemian et al., 2009c).

The soil particles, particularly mineral and colloidal parts present in peat, react with cement and pozzolanic reactions, cation exchange and flocculation take place. The pozzolanic reaction takes place with the mineral parts

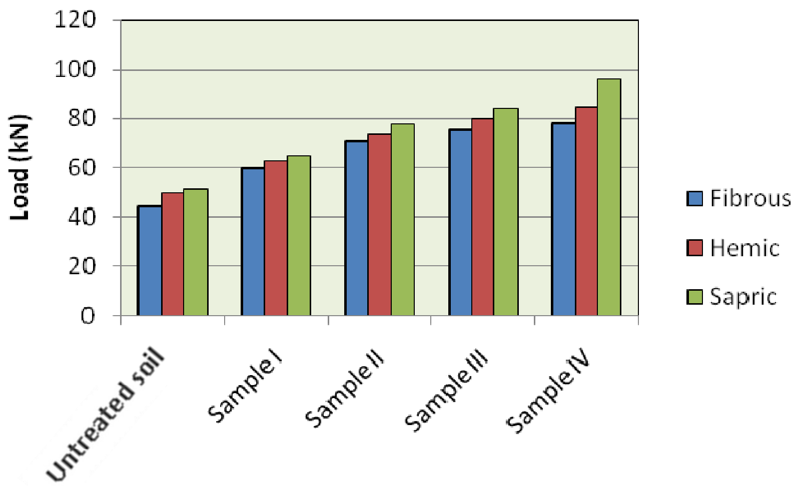

Figure 7. Ultimate load at failure of peat with full sized columns.

of peats and $Ca(OH)_2$, (although the mineral part of peat are less but cannot be ignored particularly in sapric) to form calcium aluminate silicate hydrate (C-A-S-H), which leads to an increase in the shear strength. In addition, the cement produces free calcium cations (Ca^{++}) when it comes in contact with water and Ca^{++} are absorbed by peat colloids due to their high CEC, particularly in sapric (as mentioned earlier and shown in Table 1). The CEC of sapric peat (86 meq/100 g) is higher than of hemic (71 meq/100 g) and fibrous (63 meq/100 g) peats and it appears that, the particles aggregate together to form larger particles.

As the specific surface of peat increases, a greater surface area is available (sapric peat) for cementation reactions when considered on a unit mass or volume basis; hence, a higher gain in shear strength compared with the other two peats. The specific surface areas of sapric, hemic and fibrous peat are 96, 73 and 56 m^2/g respectively (Table 1). The increase in strength parameters was observed to be more in sapric peat than in hemic and fibrous peats (as mentioned earlier). This behavior is for the reason that sapric peat has more colloidal and mineral particles, high surface area, high CEC, and high pH (Table 1) than hemic and fibrous peats; and hence can form higher number of bonds with the cement particles and attain higher shear strength. Santamarina et al. (2002) have also reported that, the engineering behavior of fine-grained soils is mostly influenced by their specific surface area.

In addition to the reasons stated above, the gain in strength by treated fibrous peat was less than the others, due to the fact that, the organic contents in fibrous peat, contain substances such as humus and humic acids in large quantity, which act as retarding materials during hydration and other chemical reactions with cement. During stabilization with cement, humic acids react with $Ca(OH)_2$ to form insoluble reaction products, which precipitate out on the particles, thus inhabiting the strength gain via reactions and also cause the soil pH to drop and hinder the cementation (Janz and Johansson, 2002).

Finite element analysis

The Rowe cell tests on untreated and treated peat samples were simulated using finite element software PLAXIS and the deformed mesh of peat and stabilized column is shown in Figure 5, as mentioned earlier. The displacement of 4.69 mm was very close to the actual recorded displacement of 4.76 mm at 50 kPa and with 10% cement. Similarly, very close agreements were observed between the actual values and the results obtained from PLAXIS for all the cases. Further, the parameters from Rowe cell test were used, to predict the ultimate bearing capacity of full size cement stabilized columns formed in peat. The stabilized cement columns used in the present simulation were 1.0 m in diameter and 5.0 m long and the deformed mesh of peat and full sized column is presented in Figure 6. The load at this displacement of 200 mm (20% of column diameter) was taken as the ultimate bearing capacity of the cement treated column in peat and the results are presented in Figure 7. The ultimate bearing capacity for all the cases, increased with an increase in the cement content. The load at failure of sapric peat was observed to be higher, than that of hemic and fibrous peats. The findings show that, PLAXIS can be used to simulate the behavior of peat in Rowe cell.

Conclusions

This study was carried out to investigate the influence of the various quantities of cement on compressibility of tropical fibrous, hemic and sapric peats by installing cement stabilized column in undisturbed peat. The following conclusions were drawn based on this study:

1. The compressibility parameters decreased with an increase in the cement content because of the hardened soil-cement matrix formed due to hydration reaction, pozzolanic reaction, and cation exchange that take place when cement comes in contact with water.
2. Compressibility parameters of stabilized peat can be improved by increasing the column-area ratio.
3. The effect of cement is higher on sapric peat among others, due to the fact that CEC, surface area, and pH of sapric peat are much higher than others.
4. From the results of PLAXIS analysis, it is apparent that the bearing capacity of peat can be increased by as high as 87.30% by using columns stabilized with 50% cement.

ACKNOWLEDGMENT

The authors wish to express their gratitude to the Ministry of Science, Technology and Innovation, Malaysia (Project No. 03-01-04-SF0889) for the financial support to the research group.

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