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Full Length Research Paper

Use of cement, polypropylene fibers and optimum moisture content values to strengthen peat

Behzad Kalantari[1]*, Arun Prasad[2] and Bujang B. K. Huat[3]

[1]Civil Engineering Department, Hormozgan University, Bandar Abbas, Iran.
[2]Department of Civil Engineering, Banaras Hindu University, Varanasi, India.
[3]Department of Civil Engineering, Universiti Putra Malaysia, Serdang, Malaysia.

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This article describes a laboratory study on strengthening peat with cement and polypropylene fibers. The study involved mixing peat with different amounts of cement, with or without fibers; compacting at their respective optimum moisture content and curing them in air for 1, 28 or 90 days. Unconfined compressive strength (UCS) and California bearing ratio (CBR) tests were performed (unsoaked and soaked samples) to evaluate the mechanical behavior of the stabilized peat. Cement and fibers can be effectively used to improve the strength of peat at its optimum moisture content. Further, since CBR is used in the design of pavement, it was observed that peat with cement and fibers can be used as the base course in the pavement construction. It appears that the fibers prevent the formation and the development of the cracks upon loading and thus increasing the strength of the samples.

Key words: Peat, stabilization, cement, fiber, optimum moisture content, unconfined compressive strength, California bearing ratio.

INTRODUCTION

Peat is usually found as an extremely loose, unconsolidated surface deposit which forms as an integral part of a wetland system, and the access to the peat deposit is usually very difficult as the water table exists at, near, or above the ground surface.

Cement has been used by researchers (Aiban, 1994; Baisha et al., 2005; Clough et al., 1981; Coop and Atkinson, 1993; Huang and Airey, 1998; Ismail et al., 2002; Kolias et al., 2005; Kazemian et al., 2011) to improve the performance of soil with low bearing capacity.

Limited studies have also been carried out by many researchers (Ahmad et al., 2010; Al Refeai, 1991; Chauhan et al., 2008; Consoili et al., 2007a, b, 2009; Gray and Ohashi, 1983; Kaniraj and Gayathri, 2003; Maher and Gray, 1990; Park, 2009; Park and Tan, 2005; Ranjan et al., 1996; Sivakumar Babu et al., 2008; Tang et al., 2007; Yetimoglu and Salbas, 2003; Yetimoglu et al., 2005) to study the influence of fiber inclusion on the mechanical behavior of cemented soil. Zhang et al. (2009) observed that the results of scanning electron microscopy (SEM) and the appearances of crack growths confirm that fibers can offer a bridging effect over the harmful pores and defects and change the expanding ways of cracks, resulting in great improvement of strength and toughness. In general, the reports in the literature show that randomly distributed fibers can be used to overcome the drawback of using cement alone such as high stiffness and brittle behavior of the stabilized soil.

Ahmad et al. (2010) have evaluated the response of randomly distributed fibers (natural and artificially coated) on the strength of sand and observed that the friction angle increased by 25% with 0.5% coated fibers of 30 mm length. Consoli et al. (2009) have carried out triaxial tests on sand added with cement (0 to 10%) and fibers (0 to 0.5%) of 24 mm length. Studies carried out by Consoil et al. (2007a) on fiber reinforced soil at large strain and by Consoli et al. (2007b) under distinct stress paths, highlight the advantages of fiber inclusion on the strength of soil. The authors concluded that the friction angle of sand could reach a value as high as 51.5° for higher

*Corresponding author. E-mail: behzad996@yahoo.com.

cement content. Park (2009) has carried out a series of unconfined compression tests on samples reinforced with fibers and reported that a fiber reinforced specimen, where fibers were evenly distributed throughout the sample was twice as strong as a non-fiber-reinforced specimen. The author has also reported that a specimen with five fiber inclusion layers was 1.5 times stronger than a specimen with one fiber inclusion layer. Tang et al. (2007) have used fiber of 12 mm length and cement to stabilize clayey soil and observed that the fiber reinforcement causes an increase in UCS, shear strength and that the fibers act as bridges, efficiently preventing the further opening of cracks, development of new ones and accordingly preventing samples from complete failure.

A study carried by Wong et al. (2008) on the cement treated and moist cured (submerged in water during curing period) peat samples shows that the gain in unconfined compressive strength of the stabilized peat specimen was only significant after a minimal dosage of 250 kg/m^3 binder with 75% (187.5 kg) cement and 25% slag (62.5 kg) used in the mixture of peat and cement. The unconfined compressive strength reached 142.5 kPa and with the amount of binder increased to 300 kg/m^3; the stabilized soil specimens yielded a higher unconfined compressive strength of 178.6 kPa. Hebib and Farrell (2003) have done a research on fibrous peat stabilization and concluded that the minimum amount of cement for strengthening to occur is 150 kg/m^3 for cement treated peat. The UCS for the moist cured cement treated peat samples was 210 kPa at the end of 28 days of curing. Kalantari and Huat (2008) have used cement and polypropylene fibers to stabilize peat samples at its natural moisture content and introduced a novel air curing technique. Kalantari and Huat (2009) used cement and polypropylene fibers to make precast stabilized peat columns to improve the bearing capacity of weak peat deposits. Also, Huat et al. (2011) used deep mixing method (DDM) to make cement stabilized columns to reinforce various types of peat. Deboucha and Hashim (2010) have also studied the engineering behavior of stabilized peat bricks with polypropylene fibers and cement. The authors have studied the UCS of stabilized peat after 3, 7, 14 and 28 days of curing. Wong et al. (2011) used cement with sodium chloride (as accelerator) and silica sand (as filler) to stabilize peat.

From the literature review, it was obvious that cement can be used to stabilize weak soils and that they can be further improved by using fibers. The reports available mainly deal in soft clay and sand, but the literature on the study of peat stabilized with cement and reinforced with randomly distributed fibers are very few.

In this model study, peat has been strengthened with ordinary Portland cement (hereinafter called cement) and polypropylene fibers (hereinafter called fibers). The stabilized peat samples were cured in air using an air curing technique that entailed letting the samples remain at normal air temperature of 30 ± 2°C and a relative humidity of 80 ± 5%, without adding water during the curing periods as detailed (Kalantari and Huat, 2008). The specific objectives of the present research are to evaluate the influence of fiber inclusion as well as use of optimum moisture content on the strength of stabilized peat by performing UCS and CBR tests on unsoaked and soaked samples.

EXPERIMENTAL PROGRAM

Test materials

The test materials used in this study are peat, cement and fibers. Peat was sourced from Kampung, Jawa in Malaysia. The properties of the in-situ peat are presented in Table 1. Cement was used as the binding agent. Fibers were used as chemically inactive additives and are shown in Figure 1 and its physical properties are presented in Table 2. This being a preliminary investigation only, fibers with only one length (12 mm) have been used in the tests.

Sampling of peat

Peat samples (undisturbed and disturbed) were collected from Kampung, Jawa in Malaysia according to AASHTO T86-90. Trial pits were excavated, depending upon the ground water table, to a depth of 0.05 to 0.45 m from the ground surface to collect soil samples. The undisturbed samples were sealed along with the samplers to prevent any moisture loss and carefully transferred to the soil laboratory without any disturbances for performing different tests like CBR, UCS, triaxial test, consolidation (Rowe cell) and permeability tests. The disturbed samples were also collected and were placed in plastic bags and were taken to the laboratory for classification and determination of index properties. The ground water table at the site is at about 0.35 m below ground surface during dry days and 0.1 to 0.15 m during rainy days.

Soil type

Grain size analysis of peat was carried out according to ASTM D5715-00 and the grain size distribution curve is shown in Figure 2. The soil was classified as fibrous as more than 66% of the peat was retained in sieve # 150 (0.15 mm).

Strength evaluation and the amounts of cement and fiber

Peat samples stabilized with cement with/without fibers were tested for unconfined compressive strength (UCS) and California bearing ratio (CBR). In order to evaluate the strength of peat stabilized with cement only, both UCS and CBR tests were carried out on undisturbed peat samples and also on peat stabilized with different amounts of cement. The amount of cement used for the UCS test was 5 and 15%, and for the CBR test it was 5, 10, 15, 20, 30 and 50% by weight of peat weighed at its optimum moisture content.

The amount of fiber to be used was decided based on the results of CBR test. Figure 3 shows the results of the CBR tests carried out on peat stabilized with 5, 15 and 25% cement and 0.1, 0.15, 0.2 and 0.5% fiber and air curing the samples for 90 days. The results show that fiber content of 0.15% gives the highest CBR values. These findings are also consistent with the findings of Kalantari and Huat (2008) where the authors used cement and the same type of fibers (Table 3), to stabilize peat at its natural water content. Based

Table 1. Properties of peat.

Property	Specification	Value
Depth of sampling		0.05 - 0.45 m
Specific gravity	ASTM D0854-06E01	1.4
Moisture content	ASTM D2216-05	98 - 417%
Bulk density (*in-situ*)		1.23 - 1.40 Mg/m^3
Classification	ASTM D5715-00	Fibrous
Liquid limit	ASTM D4318-05	160%
Plasticity index	ASTM D4318-05	Non plastic
Organic content	ASTM D2974-07a	80.23%
pH	ASTM D4972-01R07	6.81
Permeability	ASTM D2434-68R06	0.42 (m/day)
Void ratio, e_o	ASTM D7263-09	12.55
Compression index, C_c	ASTM D2850-03	4.163
Recompression index, C_r	ASTM D2850-03	0.307
Cohesion (total), c_u	ASTM D 4767-04	5.03 kPa
Friction angle (total), φ_u	ASTM D 4767-04	13.31°
Cohesion (effective), c'_u	ASTM D 4767-04	0.1 kPa
Friction angle (effective), φ'_u	ASTM D 4767-04	36.7°

Figure 1. Polypropylene fibers.

Table 2. Some properties and strength parameters of fiber*.

Property	Specification
Color	Natural
Unit weight	9.1 kN/m^3
Fiber length	12 mm
Fiber diameter	18 micron (nominal)
Tensile strength	300 - 440 MPa
Elastic modulus	6000 - 9000 MPa
Water absorption	None
Acid and alkali resistance	Very good
Softening point	160°C

*, Sika Fibers (2005).

on these findings, it was decided that a constant amount of fiber at 0.15% should be use for all the tests carried out on a stabilized soil.

Compaction tests

Modified compaction tests were carried out according to AASHTO T 180-D to find the optimum moisture content (OMC) of the untreated peat and for the peat stabilized with 5, 10, 15, 20, 30 or 50% cement. These tests were also carried out on peat with cement (5, 15 and 25% as mentioned previously) and fiber (0.15%).

Before preparing the samples, peat was dried in oven to lower its water content to around 50% as its natural water content was very high (198 to 417%). This procedure of gradual drying of natural peat samples was used instead of the usual method of complete drying of peat to prevent a possible change in the peat texture. The OMC and dry density for all the samples were calculated from the dry density-water content curves.

The samples for the compaction test were prepared by adding extra water and then adding the specified amounts of cement and fibers to keep the percentage of cement and fibers constant as it is calculated based on the wet weight of the peat. It was then put in an electric dough mixer and mixed thoroughly for ten minutes to achieve uniformity. The mixture was then placed in an automatic compaction mould and compacted as per the guidelines. The dry density-moisture content curves for untreated and stabilized peat are presented in Figure 4.

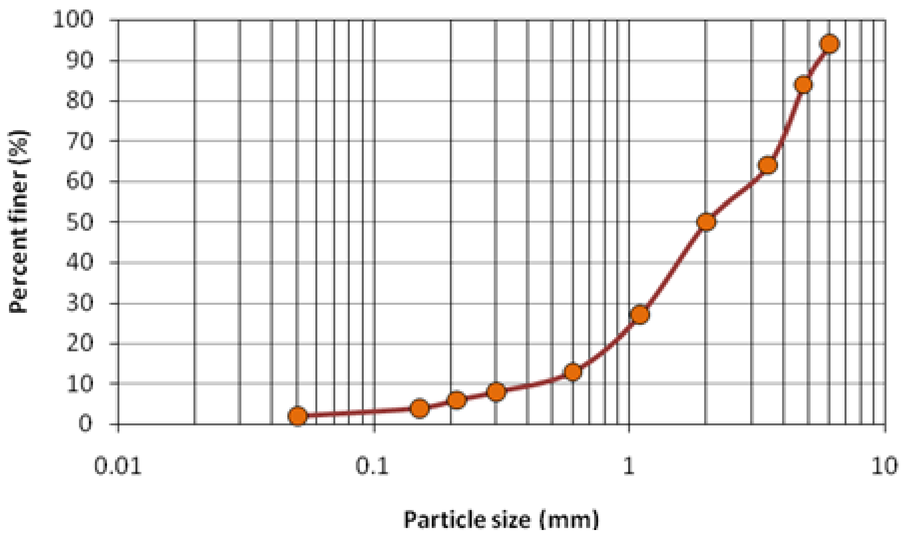

Figure 2. Particle size distribution curve of fibrous peat.

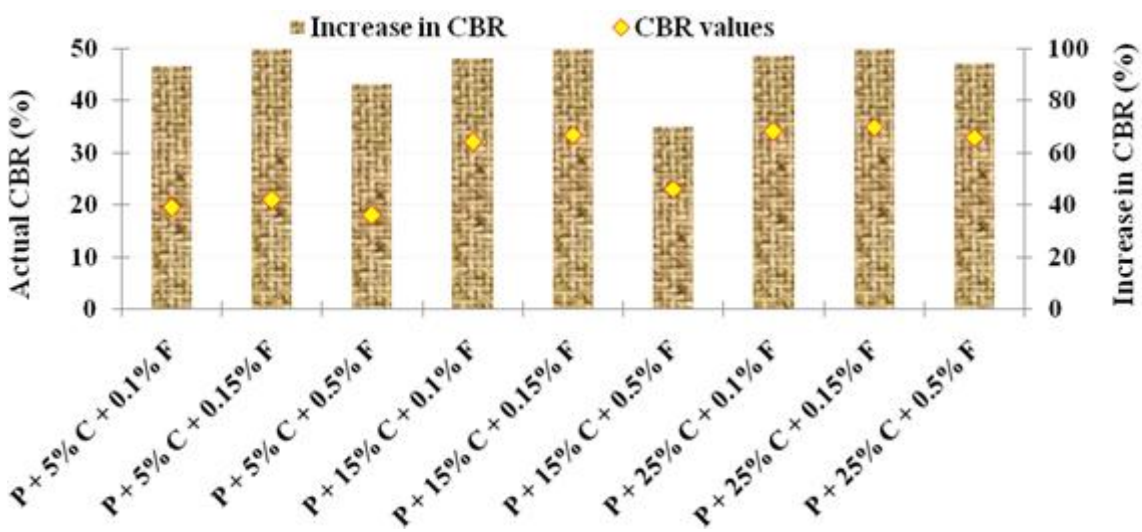

Figure 3. Percent increase and actual CBR vs. amount of cement and fiber. P, Peat; C, cement; F, fibers.

Unconfined compressive strength (UCS)

UCS tests were carried out on undisturbed peat as well as on peat stabilized with OPC according to ASTM 2166-06. The samples were prepared by adding specified amounts of cement and fiber to peat (at its OMC) and the mixture was compacted by following the standard procedure. Before adding cement and fiber, the water content of peat was determined and extra water was added to bring it up to OMC.

The mixture was compacted in a UCS mould having an inside diameter of 102 mm and length/diameter (L/D) ratio of 1.138 (4" compaction moulds) and each layer was given 56 blows of 2.27 kg (5 lb.) hammer. Also, since the L/D ratio for the samples was less than 2, a reduction factor equal to 0.89 as suggested by ASTM C 42-90 was used for the final UCS of the samples. After compaction of the samples, they were kept in open air at room temperature of 30 ± 2°C and a relative humidity of 80 ± 5% for air curing for a period of 90 days before carrying out the test. The air curing technique was adopted as it was evident that the high OMC of peat was enough for completing all the hydration reaction of cement. The UCS tests were conducted on air cured samples under two conditions; unsoaked and soaked. Soaked samples were prepared by soaking it in water for seven days and the seven days duration of soaking was based on the results obtained from the CBR test as explained previously in "California bearing ratio (CBR)". The types of UCS samples used in this research were mixtures of peat plus 5 and 15% OPC as well as peat plus 5 and 15% OPC with 0.15% polypropylene fibers.

California bearing ratio (CBR)

One of the most important parameters to be determined in any pavement design is the strength of the underlying subgrade

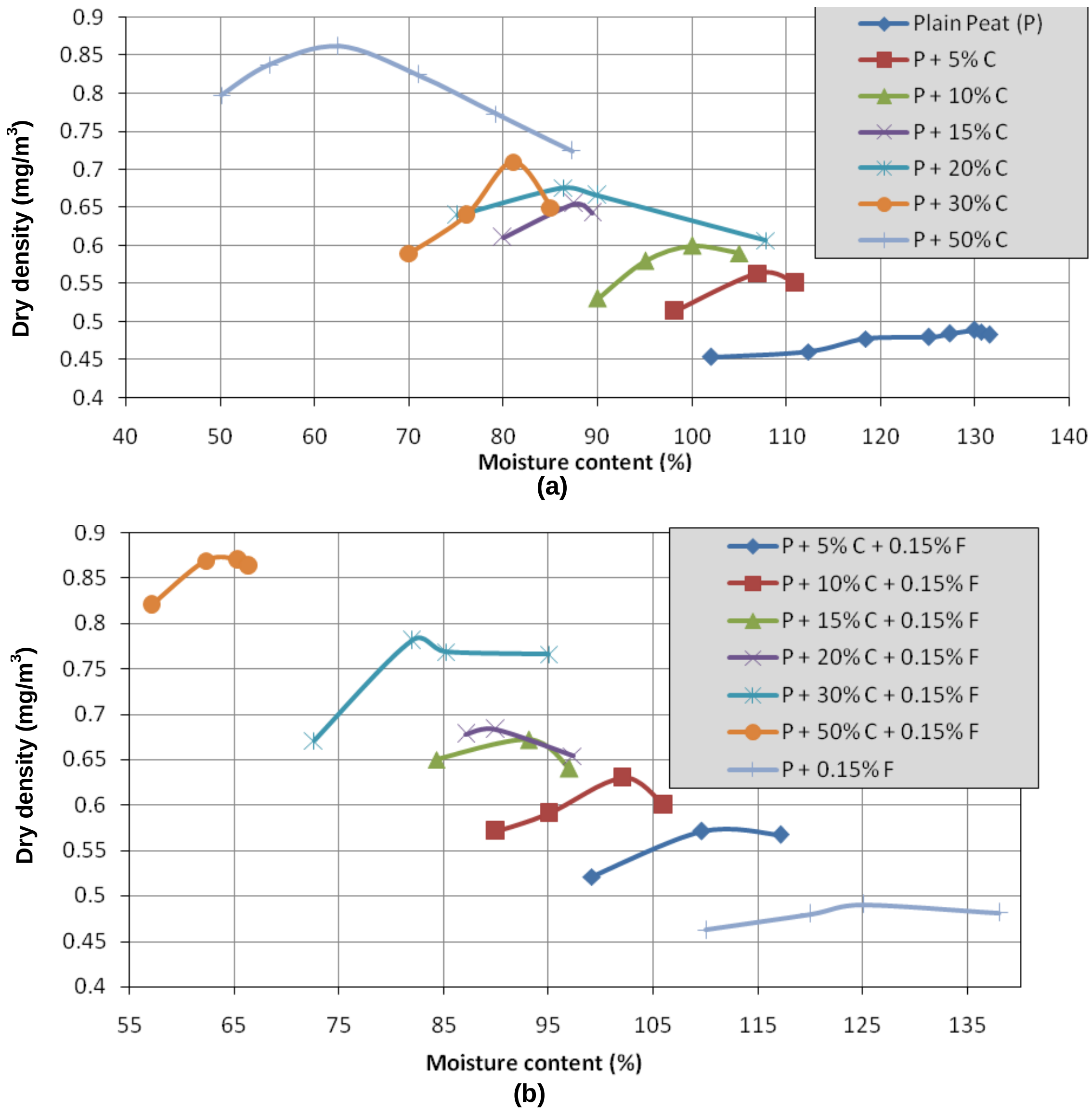

Figure 4. Dry density-moisture content curves: (a) Untreated peat and peat stabilized with cement (b) peat stabilized with cement and fiber. P, Peat; C, cement; F, fibers.

because it is to be protected from damage by building a pavement and it has the greatest influence on the structural design (Sese et al., 2005). The structural capacity of the subgrade soil can be defined in terms of CBR (Kentucky Transportation Cabinet, 2007).

Hence, CBR tests were carried out on the undisturbed peat as a control measure sample. These tests were also carried out on peat stabilized with cement with/without 0.15% fiber. The samples for CBR test were prepared according to ASTM D 1883-07E02 and cured for 1, 28 and 90 days. CBR tests were carried out on samples that were unsoaked and air cured for 1, 28, and 90 days, while soaked CBR tests were carried out on samples that were air cured for 90 days. The amount of cement used for the preparation of samples was 5, 10, 15, 20, 30 and 50%.

It was observed that all the stabilized peat samples for the CBR test, except the samples with 30 and 50% cement, reduced in diameter (shrunken) after 90 days of air curing and could easily come out its moulds. Hence, CBR tests were carried out on shrunken samples in specially prepared moulds of flexible plastic sheets with steel clamps.

CBR soaking period

The soaking period for CBR samples of normal soils is 96 h or four days according to ASTM D1883-07E02. In order to determine the CBR values of the soaked stabilized peat in this study, the soaking test was conducted on the stabilized peat samples containing 50% cement and 0.15% fibers and cured for up to 90 days. The reason for choosing this combination of stabilized soil sample, as the control measure sample for soaking test was that it showed the maximum UCS.

The procedure followed for this soaking period test was first soaking the sample in water for three consecutive weeks and during these three weeks, the soaked sample was weighed everyday for increase in weight due to an increase in saturation. After some time, the soaked sample was 100% saturated and no

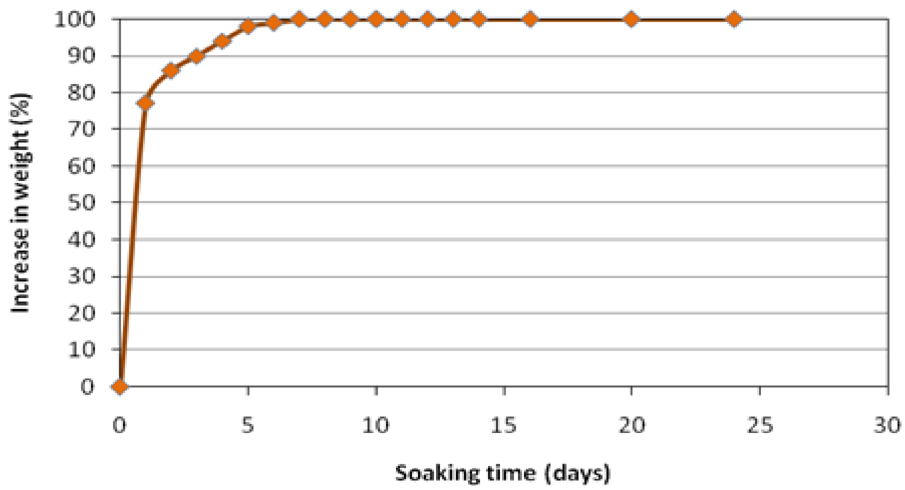

Figure 5. Percentage weight increase vs. time for samples for CBR test (soaked).

further increase in weight was observed. The number of days taken for the soaked sample to reach this constant weight during soaking was adopted as the minimum soaking period for 100% saturation for all the soaked CBR samples, and also for UCS samples. The result of this test is shown in Figure 7 and it was observed that the samples attained a constant weight after seven days of soaking. Hence, all the samples tested under soaked condition were soaked for seven days for 100% saturation.

RESULTS AND DISCUSSION

The results of the compaction test presented in Figure 4 show that as the amount of cement is increased, the dry density increases and the OMC decreases. Also, as the fibers are added to each set of peat mixtures, the OMC decreases and the dry density increases. However, the decrease in OMC and the increase in the dry density of the mixtures containing fibers are negligible when compared with mixtures without fibers.

CBR soaking period

The stabilized samples containing 50% cement and 0.15% fibers and air cured for 90 days were chosen for the soaking procedure and were soaked for 21 days. The results of this test as shown in Figure 5 indicate that the samples reach its constant weight or 100% saturation at the end of seven days. Therefore, based on this result, all the stabilized peat samples (5, 10, 15, 30 and 50% cement with and without fiber) were submerged in water for seven days before carrying out UCS and CBR tests under soaked condition.

Unconfined compressive strength

The results obtained from UCS tests on air cured samples under both unsoaked and soaked conditions are presented in Figure 6. It is observed that when the cement content increases from 5 to 15%, the UCS values for unsoaked and soaked samples increase as well. As expected, it is observed that the UCS of samples soaked condition is less than that under unsoaked condition. It is also observed that the addition of 0.15% fibers to the samples increases the UCS values compared with samples without fibers.

Based on the results shown in Figure 6, it is observed that the UCS of unsoaked and soaked samples stabilized with cement is improved as the cement content is increased. It is also observed that even with a minimal use of cement (5%, that is, less than 60 kg/m^3) with peat, the UCS of unsoaked samples can reach 300 and 100 kPa for soaked samples after 90 days of curing, as compared with 28.5 kPa for untreated peat. The UCS increases from 28.5 kPa for undisturbed peat to 380 kPa for peat stabilized with 15% cement and 0.15% fiber for the unsoaked condition and to 300 kPa for the soaked condition. Wong et al. (2008) have reported UCS of cement treated peat to be 142.5 kPa and the cement content was 187.5 kg/m^3 whereas, Hebib and Farrell (2003) have used 150 kg/m^3 cement and the UCS of peat reported was 210 kPa. The strength achieved in the present research is higher that the strength achieved by other researchers. Tang et al. (2007) have also reported an increase in UCS of soil upon treatment with cement and fibers.

It is also imperative that the strength of the samples increase with an increase in cement content as this acts as a binding agent. Further, cement hydration with soil pore water produces cementation gel and reduces calcium hydroxide. This calcium hydroxide will disassociate and raise the pH of the soil. It is understood that the higher pH value of the peat will favor the initial cement reaction and also favor the long term pozzolanic reaction. The gain in strength is governed by the ratio of

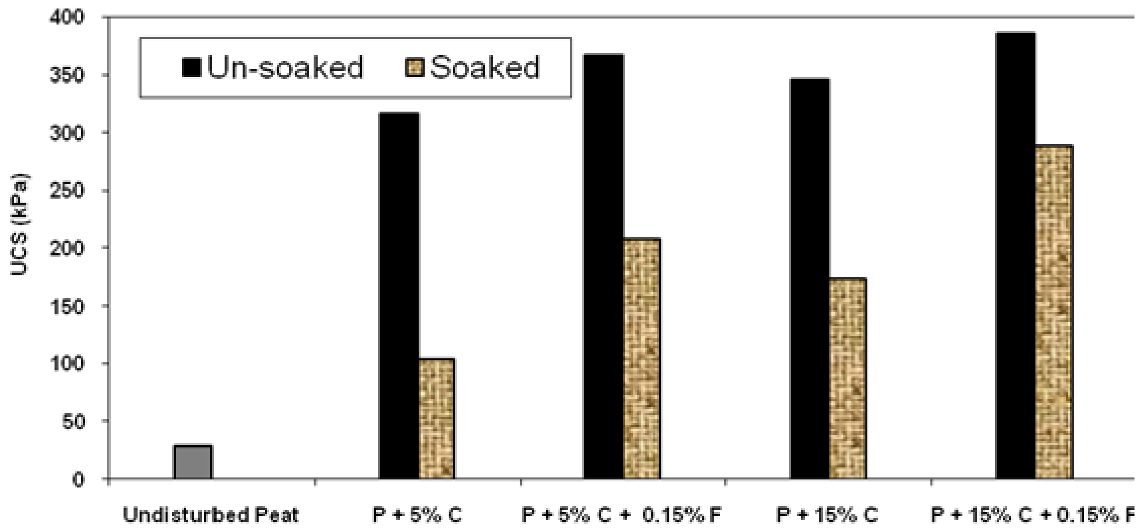

Figure 6. UCS of peat stabilized with cement and fiber. P, Peat; C, cement; F, fiber.

C_3S to C_2S besides some other parameters. Factors affecting stabilized 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 the nature or the type of the organic matter. The strength gained for cement stabilized peat will also depend upon the decomposition of the organic compound to organic acid due to the effect of biological influence.

This behavior of peat may also be for the reason that when the soil particles, particularly clay present in peat, react with cement, cation exchange and flocculation takes place and these are responsible for the improvements in strength and load-deformation behavior. The cement produces free calcium cations (Ca^{2+}) when it comes in contact with water and replaces dissimilar adsorbed cations on the colloidal surface. It is reported that high concentration of Ca^{2+} and OH^- ions is created in the cement-soil matrix immediately after addition of water to the cement (Duraisamy et al., 2006). With passage of time, there is growth in the amount of C-S-H gel formed resulting in bonding among the soil particles. Practically all fine-grained soils display rapid cation exchange and flocculation-agglomeration reactions when treated with cement in the presence of water. These processes that change the electrical charge density around the soil particle cause changes in the behavior of the aggregated soil. When soil-cement is compacted, chemical bonds develop between adjacent cement grain surfaces and between cement grain and soil particle interfaces. Not only does cement destroy the soil plasticity, it also increases the shear strength and reduces the water holding capacity of clayey soils (Eades and Grim, 1960; Kazemian and Huat, 2009; Axelsson et al., 2002). Further, it also appears that the randomly distributed fibers limit the potential planes of weaknesses and also prevent the development of the cracks upon loading and thus further increases the UCS.

California bearing ratio

The CBR values obtained for undisturbed peat, non-stabilized peat and peats stabilized with fibers and air cured for 1, 28 and 90 days are presented in Figure 7. The results indicate that as the curing period increases, the CBR values increase as well. With the increase in cement content from 0 to 50%, the CBR values are also increasing. Further, an addition of 0.15% fibers to the cement stabilized peat samples increases the CBR values over samples without fibers.

The results show that the CBR increases from 0.8% for undisturbed peat to 145% for peat stabilized with 50% cement and 0.15% fiber. This increase in CBR values can be attributed to the OMC at which the samples were compacted and to the cement and fibers for increasing the strength of the samples. Results shown in Figure 7 indicate that the curing period has a significant effect on the CBR strength of stabilized peat. It appears that due to the hydration process (hardening process of cement) and evaporation of water during the air curing process, the water-cement ratio (W/C) of the cement treated peat samples decreases and results in a higher strength of the samples. Rathmayer and Valasti (2007) have also pointed out that the strength of stabilized organic soil is strongly dependent on the water-cement ratio.

The results of unsoaked and soaked CBR values obtained for undisturbed peat and stabilized peat after air cured for 90 days are presented in Figure 8. It is observed that by stabilizing and air curing the soil

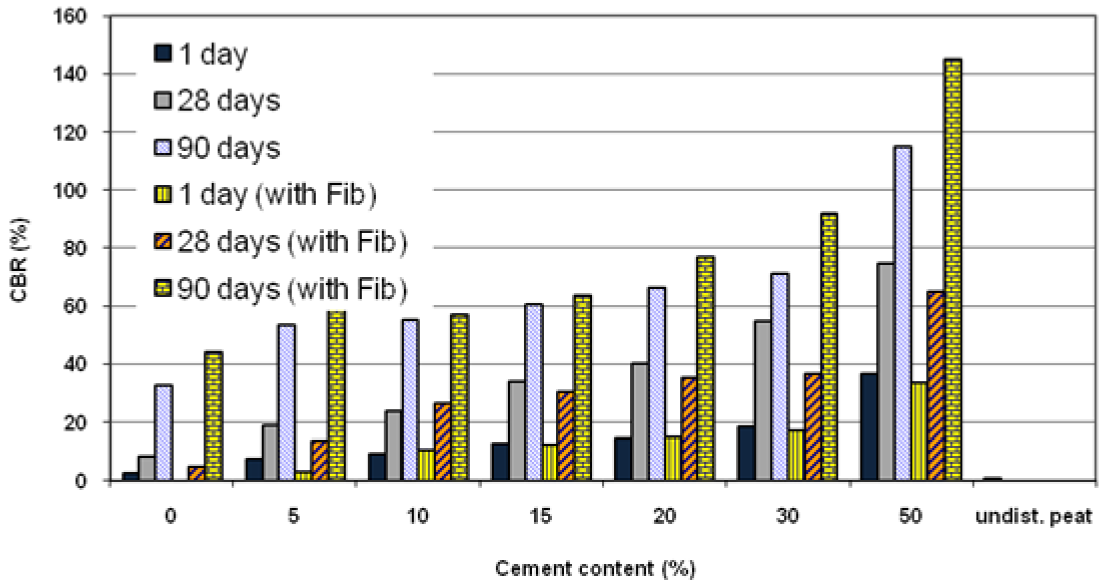

Figure 7. CBR of stabilized peat after different air curing period.

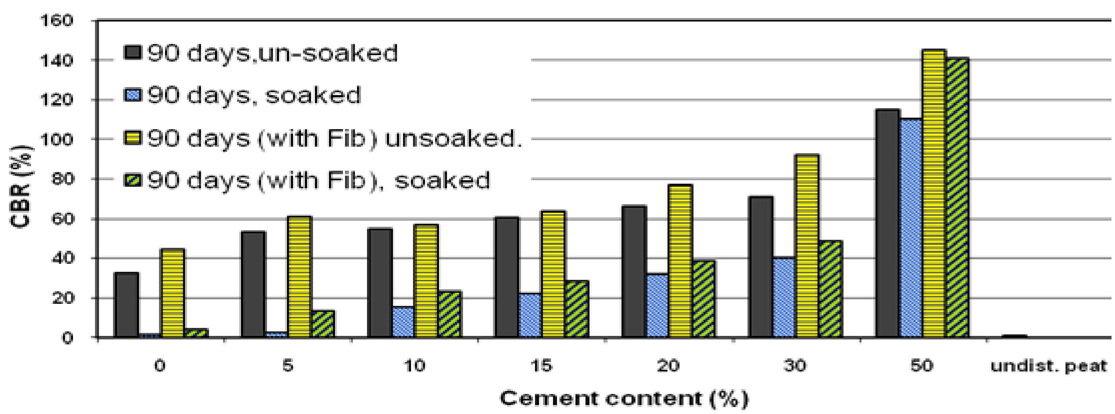

Figure 8. CBR of stabilized peat after 90 days of curing (unsoaked and soaked).

samples, CBR values of in-situ soil can be increased from very poor (0 to 3%) to fair and good (7 to 20% and above) (Bowles, 1978). Also, when the fibers are added to the stabilized peat samples, the 90 days unsoaked and soaked CBR values increase as well. This shows that cement and fibers can be used effectively for improving the strength of the base course for the pavement construction.

Visual inspection of stabilized peat samples after each test indicated that the samples containing higher cement appeared to be more uniform and intact as cement is a binding agent. Addition of the fibers to the samples had probably caused the stabilized samples to be even more uniform and intact with fewer and smaller cracks, and this was in accordance with the findings of Kalantari and Huat (2008).

Conclusions

Peat is one of the softest soils and is unable to resist construction loads imposed on it. In this study, peat was stabilized with cement as a binding agent and fibers as a chemically inactive additive. The stabilized samples were cured in air, instead of normal curing methods, as its natural water content was very high. Based on the study, the following conclusions can be drawn:

1. Air curing method is a potential method of curing peat stabilized with cement and with/without fibers.
2. The UCS and CBR of the cement stabilized peat samples, compacted at their respective OMC, increased by a factor as high as 9.5 and 75, respectively. This shows that cement (15%) can be used to improve the

strength of peat.
3. It is observed that the cement (15%) and fiber (0.15%) increased significantly the UCS and CBR values by a factor 13.5 and 79, respectively and hence, it is obvious that fibers can be used to increase the strength of peat.
4. It appears that the randomly distributed fibers limit the potential planes of weaknesses and also prevent the formation and the development of the cracks upon loading and thus increasing the UCS and CBR.
5. Cement and fibers can be used effectively to improve the strength of base course for the pavement construction.

FUTURE SCOPE OF RESEARCH AND ITS LIMITATIONS

Peat is found in many countries and given the rising cost of land for the construction, it becomes imperative to improve its engineering behavior. Cement and fibers appear to be promising materials for peat improvement. Future research can be carried out using fibers other than polypropylene fibers to further improve the bonding or friction developed along the fiber surfaces. Cement, being expensive material, some other types of binders or fillers can also be utilized. The present research is carried out on fibrous peat. The behavior of different types of peat, including fibrous, hemic and sapric will be different as the quantity of binders required will depend upon the particle size. Hence, future work can be extended to other types of peat.

The main limitation of this research is the non-applicability of findings on a large scale. The researchers have agreed that the findings are applicable only for local peat and the research needs to be carried out for different localities due to a wide variation in peat properties.

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