Sains Malaysiana 45(11)(2016): 1679–1687

Effect of Cement Additive and Curing Period on Some Engineering Properties of Treated Peat Soil

(Kesan Aditif Simen dan Tempoh Perawatan terhadap Beberapa Sifat Kejuruteraan Tanah Gambut Terawat)

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ABSTRACT

Peat soil is characterized by its high content of decomposed organic matter. Majority of areas occupied by peatland have been developed for agriculture sectors such as pineapple cultivation and oil palm. Due to its geotechnical drawback characteristics such as highly compressibility and low shear strength, peat soil is classified as problematic soils and unstable for engineering structures. Lack of suitable and expensive price of lands, peatland will be an alternative option for future development. Prior to construction works, stabilization of peat soil should be performed to enhance its engineering characteristics. This paper presents the effect of cement and curing period on engineering properties of the cement-treated peat soil. Some engineering variables were examined including the compaction behaviour, permeability and unconfined compressive strength (UCS). The Atterberg limit test was also carried out to examine the influence of cement addition on peat soil. The cement-treated peat soils were prepared by adding varying amount of ordinary Portland cement (OPC) ranging between 0% and 40% of dry weight of peat soil. In order to examine the effect of curing, the treated samples were dried at room temperature for three and seven days while for UCS tests samples were extended to 28 days prior to testings. The results showed that the liquid limit of treated soil decreased with the increase of cement content. Maximum dry density (MDD) increased while optimum moisture content (OMC) dropped with the increase in cement content. Permeability of treated soil decreased from 6.2×10^{-4} *to* 2.4×10^{-4} ms^{-1} *as cement content increase from 0% to 40%. In contrast, the UCS tests indicated an increase in uncompressive strength with the increase in cement contents and curing period. The liquid limit and permeability were also altered as curing periods were extended from three to seven days. This study concluded that geotechnical properties of peat soil can be stabilized using ordinary cement and by modification of the curing periods.*

Keywords: Curing; peat soil; Portland cement; treated soil; unconfined compressive strength

ABSTRAK

Tanah gambut dicirikan oleh kandungan reputan organiknya yang tinggi. Kebanyakan kawasan tanah gambut telah dibangunkan untuk sektor pertanian seperti penanaman nenas dan kelapa sawit. Akibat daripada kelemahan sifat geotekniknya seperti kebolehmampatan yang tinggi dan kekuatan ricih yang rendah, tanah gambut dikelaskan sebagai tanah bermasalah dan tidak stabil untuk struktur kejuruteraan. Kekurangan tanah yang sesuai dan harga yang mahal menyebabkan tanah gambut merupakan pilihan alternatif bagi pembangunan pada masa hadapan. Sebelum kerja pembinaan dijalankan, penstabilan tanah gambut perlu dilakukan untuk meningkatkan ciri geoteknikal. Kertas ini membincangkan peranan simen dan tempoh perawatan ke atas sifat kejuruteraan tanah gambut terawat. Beberapa parameter kejuruteraan diuji terdiri daripada lakuan pemadatan, ketelapan dan kekuatan mampatan tidak terkurung (UCS). Ujian had Atterberg juga dijalankan bagi melihat pengaruh simen terhadap tanah gambut. Tanah gambut terawat simen telah disediakan dengan menambahkan simen Portland biasa (OPC) pada jumlah yang berbeza antara 0% dan 40% terhadap berat kering tanah gambut. Untuk menguji kesan perawatan, sampel terawat dikeringkan pada suhu bilik selama tiga dan tujuh hari manakala bagi UCS dilanjutkan kepada 28 hari sebelum pengujian. Hasil kajian menunjukkan bahawa had cecair tanah yang terawat menurun dengan peningkatan kandungan simen. Ketumpatan kering maksimum (MDD) meningkat manakala kandungan lembapan optimum (OMC) menurun dengan peningkatan dalam kandungan simen. Kebolehtelapan tanah yang terawat menurun daripada 6.2×10^{-4} *kepada* 2.4×10^{-4} ms^{-1} *dengan kandungan simen meningkat daripada 0% hingga 40%. Sebaliknya, ujian UCS menunjukkan peningkatan dalam kekuatan dengan peningkatan kandungan simen dan tempoh perawatan. Had cecair dan ketelapan juga berubah dengan peningkatan tempoh perawatan. Kajian ini menyimpulkan bahawa sifat geoteknikal tanah gambut distabilkan dengan penggunaan simen biasa dan pengubahsuaian tempoh perawatan.*

Kata kunci: Kekuatan mampatan tidak terkurung; simen Portland; tanah gambut; tanah terawat

Introduction

Peat soil is high in organic matter which originated from decomposition of plants through humification process (Hartlen & Wolski 1996). The disintegration of plant in acidic environments without microbial activity generates highly organic matters in peat soil (Wong et al. 2008). Peat soils can occur both in lowland and highland areas, however highland peat soils are not extensive. Most of the lowland peats have developed along the coast, behind accreting mangrove coastlines (Wetlands International 2010). In Malaysia, peat soil areas represent 2.7 million ha and this value is 8% of the total area of Malaysia (DIDS 2008). The distribution of peat soils are mostly situated near to coastal areas of Johor, Pahang, Selangor and Perak. Sarawak has the largest peat soil in Malaysia that covers 1.66 million ha, representing 13% of the state area (Said &Taib 2009). Many areas occupied by peat soil have been developed for agriculture sectors such as pineapple cultivation and oil palm plantations (Abu Bakar 2007; Mutert et al. 1999; Silvius 2007). The conversion of peat lands to agricultural activity have soared for the past two decades. In Peninsular Malaysia and Sarawak, the cultivation of peat lands for agriculture is represented by 32% and 31% of total peat land area, respectively (Abdul Jamil et al. 1989; Melling et al. 1999).

Peat soil is classified as among the problematic soils due to its high compressibility, high in natural moisture content and low shear strength. The bearing capacity of peat soil is very low and apparently controlled by the water table and presence of subsurface woody debris (Andriesse 1988; Islam & Hashim 2008). Its moisture content can achieve up to 800% and it is usually found in dark brown to black colour (Kolay & Pui 2010). Wong et al. (2008) also stated that the water holding capacity of peat soils in Peninsular Malaysia is very high. Therefore, in its natural occurrence, peat soil is considered unsuitable material for supporting foundations (Hashim & Islam 2008a). Construction and building on peat soil areas are often avoided whenever possible (Huat et al. 2005). It is commonly reported that tropical peat soils associated with highest settlement when subjected to a load over long period (Duraisamy et al. 2007). SEM observation on untreated peat soil consisted of many sheet-like particles that likely attribute to high compressibility and limited strength (Nontananandh et al. 2002; Tang et al. 2011). However, construction on peat soil has become increasingly necessary due to limited of suitable and higher cost of lands. Prior to construction, the conditions of peat soil have to be improved in order to overcome any problem related to settlement and surface subsidence.

A number of options were suggested for construction on peat and organic soils (Edil 2003). One of the options recommended was addition of chemical such as cement and lime. The utilization of chemical additive can be applied either as a deep *in situ* mixing (lime-cement column) or as a surface stabilizer. Cement has been used extensively as stabilizer additive for wide range of soils (Duraisamy et al. 2009; Hashim & Islam 2008b; Lo & Wardani 2002; Lorenzo & Bergado 2004). It offers quick stabilization, short mellowing time and provides a non-leaching platform (Soriosseiri & Muhunthan 2009). The volume, stability and strength of the treated soil can be modified through the chemical reaction between additives and soil (Kolay et al. 2011; van Impe 1989). Deboucha et al. (2008) stated that the maximum dry density and unconfined compressive strength of peat soils were improved when stabilized with cement and sand. Huat et al. (2005) mentioned the significant improvement in unconfined compressive strength for treated peat soil with cement and lime. It was also found that the longer the curing period, the performance of treated peat became better. In this study, ordinary Portland cement (OPC) was used as an additive material to improve geotechnical properties of peat soil. OPC is a mineral-based material possesses pozzolanic reactivity. As soil is treated with OPC, the strength gained in the soil is a fully dependent on the slow pozzolanic reactions, which are normaly completed in maximum 28 days (Teja et al. 2015). The chemical reaction between calcium hydroxide (lime) and water will lead to the formation of hydrate compound that posses cementing property. Addition of lime will increase the soil pH above 10.5 that enables the break down of clay particles, releasing the silica and alumina (Zukri 2013). OPC contains tri-calcium silicate (C_3S) that reacts with water to form the hydrated C-S-H compound of $C_3S_2H_3$ (Bergado 1996). This cementing characteristic can be an advantage to improve problematic soils such as peat soil.

In this study, the effects of cement on the index and engineering characteristics of peat soil were examined. OPC was added at ratios 0, 10, 20 and 40% of the dried weight of peat soil. Some of the geotechnical characteristics of treated soil were studied including Atterberg limit tests, compaction, permeability and shear strength.

Materials and Methods

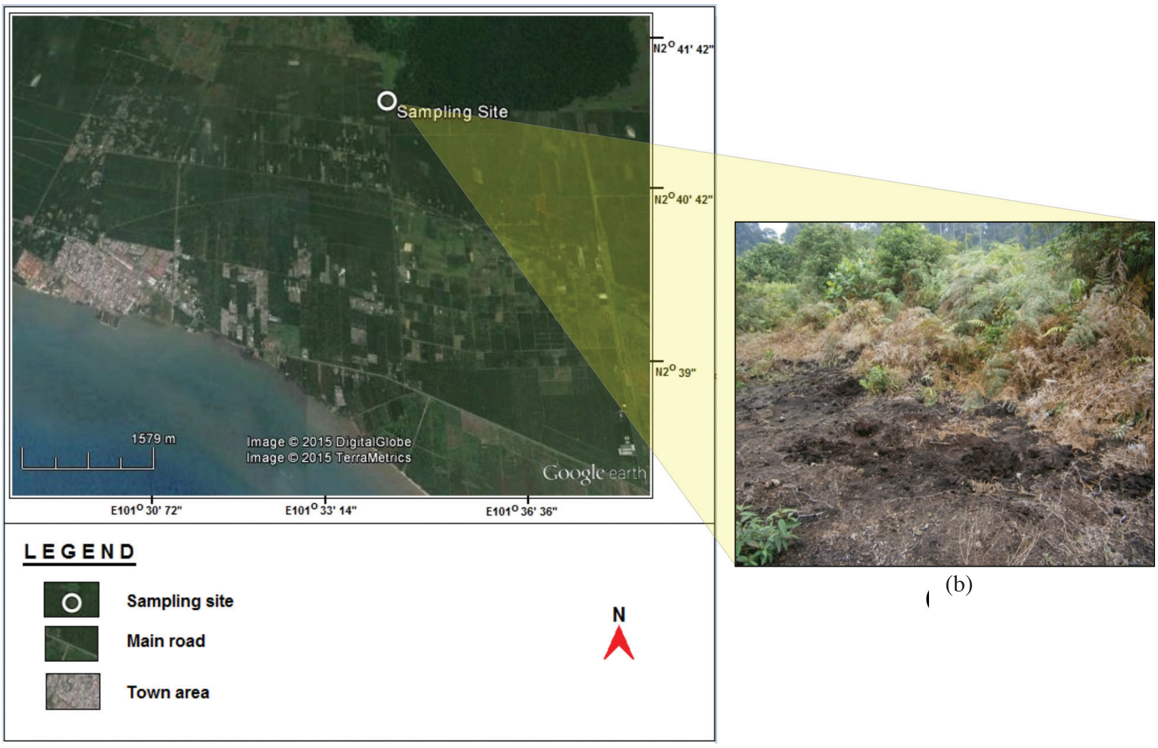
Materials Used

The collection of peat soil samples were carried out at Kampung Tumbuk Darat, Sepang Selangor, situated at 2°40´48.6˝N and 101°35´45.8˝E (Figure 1). Undistured samples were collected at a meter depth of open trench using metal core sampler. Core samplers were pushed down into soil and were carefully taken out to minimize disturbance to the peat samples. Paraffin wax was used to seal both openings to restore the natural moisture content of the sample. Samples were wrapped with plastic film, labelled and stored in plastic container. The undisturbed samples were collected for determination of the field moisture content and shear strength. Shear strength coefficient was determined from the unconsolidated undrained (UU) test. Sufficient amount of bulk sample of peat, weighing about 100 kg was also collected from the same trench, stored in airtight container and transferred to the laboratory. Bulk samples were air-dried under room temperature environment for a week. Aggregates from dried samples was gently broken down by hand and crushed by pestle and mortar to individual grains. Then, the samples were sieved to pass through 2 mm sieve sizeas recommended by USDA (2014). This soil fraction is where most reactive soil surface is found that control the soil behaviour. These samples were used to determine the basic characteristics of untreated peat soil and become a stock for the preparation of cement-treated peat soil for the engineering characterization. Scanning electron microscope (SEM) facility (Philips, model XL30) was used to observe the microstructure patterns of the natural peat and cement-treated peat soil samples. This equipment can magnify image up to 100000 times with 2.5 nm resolution.

Ordinary Portland cement (OPC) was used in this study as a binder agent to modify the mechanical behaviour of peat soil. This product is commonly available in market and has been regularly used in chemical stabilization for many soils (Axelsson et al. 2002; Hashim & Islam 2008a; Sarisseiri & Muhunthan 2009). OPC is a type of hydraulic cement and it will set and harden by reacting chemically with water through hydration. Chemically, OPC contains small amount of gypsum (calcium sulphate dehydrate) and/or anhydrite (calcium sulphate). Particle distribution analysis indicated that OPC is classified as silty clay (CM). Tang et al. (2011) noted that the particle distribution of OPC ranged between 5 and 15 µm. The fineness nature of OPC particles enables them to occupy the inter-particle spaces of peat soils as can be seen in Figure 2(b). Hashim and Islam (2008b) and Huat et al. (2005) cited that cement stabilized peat posed denser soil structure as a result of pozzolanic materials developed in treated peat soil.

PREPARATION OF OPC-TREATED SAMPLE

The preparation of treated soil samples were carried out by dry mixing peat soil with OPC at percentages between 0 and 40% of dried weight of peat soil. A hand held mechanical mixer with torque motor of 1050 W and speed ranges between 0 and 580 rpm was used to homogenize the mixture and was carried out for 10 min. Then, the treated soil samples were kept in airtight plastic container and became a stockpile for preparing samples for the engineering parameters. Preparation of treated samples for the permeability and unconfined compressive strength (UCS) tests were carried out innon-ferous 1 L cylinderical compaction mould with 105 mm internal diameter and 115.5 mm height (BS ligth). The UCS samples were extruded with core sampler from the compaction mould and would let to dry at room temperature for curing. The core samples used for the UCS tests are 38 mm in diameter with height of 80 mm. Three samples were prepared for each percentage of OPC content with total of 24 samples (three and 28 days curings). For the permeability tests, the samples prepared in the compaction mould were straight away set up for the falling head permeameter after curings are completed. Each test requires three samples for replication of the data. A total of 24 samples were also prepared for permeability test. In order to examine the influence of curing periodon permeability, these treated soil samples were dried at room temperature for three and seven days.



(a)

FIGURE 1. (a) Location of the peat soil samples and (b) site view of peat soil exposure

Testing Procedures for Treated Peat Soil

The treated peat soils were examined for their Atterberg limit, compaction, permeability and strength. Four sets of treated samples were prepared and each set consisted of OPC between 0 and 40% of dry weight peat soil. The samples tested for permeability testswere cured for three and seven days, whereas for UCS tests were cured for three and 28 days in order to establish the effect of cement contents and curing periods on treated peat soils. Due to limited samples and time, the curing period for the permeability testson the treated peat soil was limited three to seven days.

In determination of the Atterberg limit, the plastic limit, w_p of the peat soil was not possible to determine since peat is non-plastic due to the highly occurrence of plant remnants (Kolay et al. 2011). Non-plastic peat soil is characterized by very low strength and highly fragile at dry state. Therefore only the liquid limit was determined for the peat sample in this study due to its non-plastic characteristic. The liquid limit, w_l was determined using the Casagrande technique based on BS1377 (British Standard Institution 1990a). The sample was placed in Casagrande cup and 13 mm wide groove was halved the sample. Then the cup was dropped repeatedly on the base until the groove closes and numbers of drop were recorded. The representative samples were then collected to determine the moisture content at liquid limit. Liquid limit value is equivalent to 25 blows or drops.

The compaction tests were carried out according to the standard Proctor 2.5 kg of compaction effort (or BS light) based on the BS 1377 (British Standard Institution 1990b). This test aims to determine the values of maximum dry density, ρ_{dmax} and optimum moisture content, w_{opt}. Each test required approximately 2.5 kg of treated soil sample. Soil sample was placed in metal compacted with 2.5 kg rammer dropped at high of 30 cm. Twenty five blows were applied on each layer and the blows continues up to three uniform layers. Representative samples were picked up to determine the moisture content. A similar procedure was performed for samples with higher moisture content. A compaction curve was plotted to determine the values of ρ_{dmax} and w_{opt} for each treated peat soil with different OPC contents.

The permeability tests were performed on treated samples based on the technique recommended by BS 1377 (British Standard Institution 1990c). Prior to setting up samples in falling head permeameter, soil samples were prepared in a standard compaction test mould. After curing periods of three and seven days, the cylindrical samples were placed in soaking tank and slowly fill with deaired distilled water. The top cap of the sample was then connected to small vacuum pressure of 50 to 75 mm of water. This stage of saturation was applied for 24 h or until deaired distilled water is drawn from the sample. For the untreated peat, the saturation was completed within 24 h while for 10, 20 and 40% of OPC-treated samples, the saturation required between three and 10 days.

The UCS tests were also carried out on the treated peat soil samples. The samples for UCS tests were prepared by compaction at maximum dry density, ρ_{dmax} and optimum moisture content, w_{opt}. A total of twelve samples were prepared in the standard compaction mould. For curing purpose, the samples were let to dry at room temperature for three and seven days. UCS tests were then performed after each curing period in accordance with ASTM standard method D 2166 (ASTM 1994).

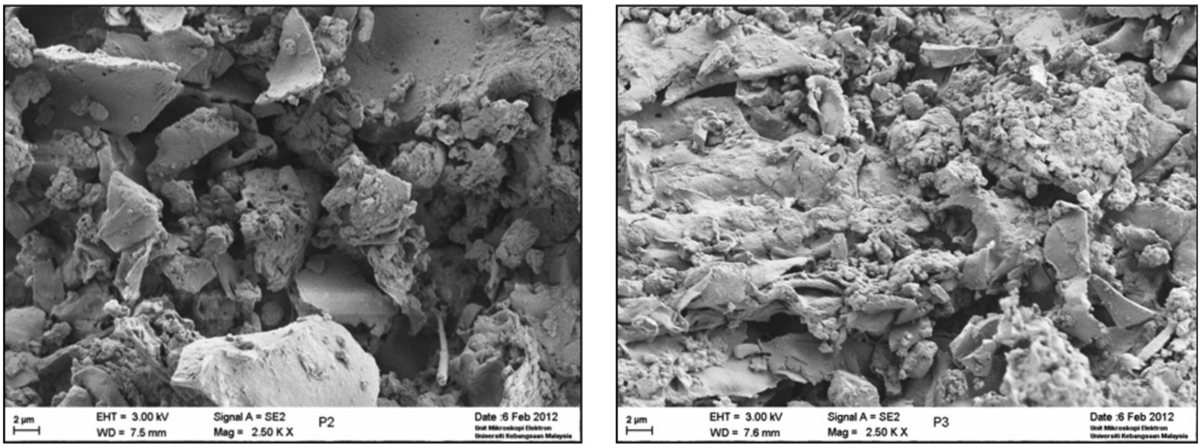
Results and Discussion

Basic Characterization of Peat and Ordinary Portland Cement

Visual observation of peat soil is characterized by its dark brown in color as a result of high content of organic matter (Figure 1(b)). By squeezing the peat soil between fingers, a cloudy and clay-like paste escaped between fingers, leaving plant structures. The plant structures can be traced but hardly recognized from the peat residue. According to von Post classification, the peat soil can be classified between H_5-H_6 (Landva & Pheeney 1980; Van Post 1922). Through field characteristics, the peat can be categorized as a moderately to highly decomposed with indistinct present of plant structure. The basic characteristics of untreated peat soil are shown in Table 1. SEM analysis on indicated that the texture of untreated peat is dominated by sheet-like particles representing the organic fibers (Figure 2(a)). Fibers are characterized by the occurrence of different internal cellular structure of organic material (Kaya et al. 2013). Platy clay minerals are also present as well as quartz minerals (Figure 2(a)). It contains vast amount of inter-particle pores that contribute to its structural weakness. The remnants of plant fibres can be seen between flaky shape particles of clay minerals. The treated peat soil showed soil structure with densely pack characteristic if compared to that of untreated soil (Figure 2(b)). Tang et al. (2011) decribed that a substantial growth of cementious materials that harden on surface of stabilized soil can increase in strength of treated peat soil.

Peat soil has low pH value of 3.51 and its organic content almost over 95%. The highly acidic nature of peat soil is due to the decomposition of organic matters that responsible in secretion of organic and humic acids into the soil (Huat et al. 2005; Shamshuddin 1981). Based on the organic content, the soil can be classified as highly organic fibrous peat. The specific gravity, G_s of peat soil is generally low (1.25) with natural moisture content of more than 100% (Table 1). The liquid limit, w_l is highly caused by the presence of high organic content. Plastic limit could not be defined due to fibrous nature of the peat soil used in this study. Compaction test on the peat soil indicated its low maximum dry density, ρ_{max} and optimum moisture content,w_{opt}. As a result of its nature, the shear strength, C_u of peat soil found to be very low of 11 kPa.

OPC shows pH of high alkalinity with a mean specific gravity of 2.8 (Table 1). Similar value was also reported



(a) (b)

FIGURE 2. SEM micrographs of (a) untreated and (b) OPC-treated peat soils

TABLE 1. Basic properties of the untreated peat soil and cement

Property	Peat	Cement
pH	3.51$^{\alpha}$	12.7$^{\alpha}$
Particle size distribution	-	CM$^{\delta}$
Specific gravity, G_s	1.25$^{\alpha}$	2.8$^{\alpha}$
Organic content (%)	97.42$^{\alpha}$	-
Grade of decomposition	H_5-H_6	-
Natural moisture content, w (%)	470 – 560	-
Liquid limit, w_l (%)	184	-
Plastic limit, w_p (%)	-	-
Max. dry density, ρ_{max} (g/cm^3)	0.61$^{\alpha}$	-
Opt. moisture content, w_{opt} (%)	63.5$^{\alpha}$	-
Shear strength, C_u (kPa)	13.8	-

$^{\alpha}$- Mean value, $^{\delta}$- Silty clay

by Basha et al. (2004) and Jayawardane et al. (2012). The mineralogy of cement changes when water is mixed and CSH (calcium silicate hydrate) develops end up with modification of fabric structure. The SEM micrograph of the OPC-treated peat soil is shown in Figure 2(b). The soil structures appear to be more packed arrangement where soil particles are binded and inter particle spaces are filled with cement. As seen in SEM image, the CSH occupies the inter-particle spaces and bridging between soil particles.

EFFECT ON LIQUID LIMIT

The effects of cement and curing period on liquid limit, w_l can be seen in Figure 3. As stated earlier, the plastic limit, w_p could not be achieved because of non-plastic nature of peat soil, thus the plasticity index, I_p could not be determined. Very small clay content may not establish reliable results of w_p even the peat at high humification of below H_5 (Skempton & Petley 1970; Whitlow 2001). For non-plastic peat soil, the I_p values range between 0 and 3 (Sowers 1979).

The untreated peat soils were indicated by high values of w_l as a result of the high content of organic component (Table 1). The occurrence of high organic matter causes the increase in the water absorption capacity of peat soil (Kolay et al. 2011). Huat et al. (2009) stated that the liquid limit of peat soil increases with the increase in the amount of organic content. Treatment of peat soil with different amounts of OPC (i.e. 0, 10, 20 and 40%) showed the values of w_l decrease with the increases in OPC contents (Figure 3). The reduction of w_l values were due to hydration of cement which generated cementation (pozzolanic reaction) between inter-particle spaces of peat soil (Bediako & Frimpong 2013; Deboucha & Hashim 2009). Similar behaviors were also stated by previous studies indicating that cement-treated soils are characterized by denser soil structure if compared with that of untreated samples (Eriktius et al. 2001; Mohidin et al. 2007).

EFFECT ON COMPACTION BEHAVIOUR

The results of the compaction tests are shown in Table 2. Meanwhile the compaction curves for untreated and treated peat soils are shown in Figure 4.

Treatment of peat soils with OPC indicated an increase in maximum density, ρ_{dmax} however the optimum water content, w_{opt} showed erratic values. The values of ρ_{dmax} and w_{opt} of untreated soil were 0.61 g/cm^3 and 63%,

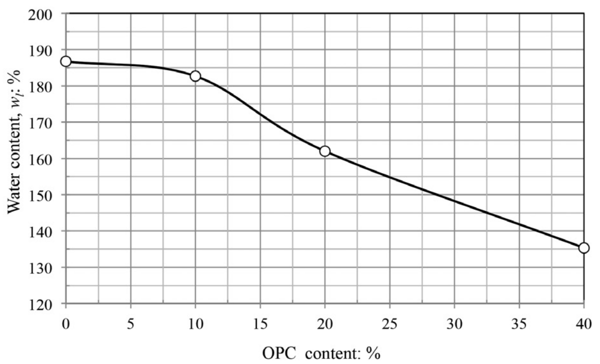


FIGURE 3. Liquid limit of OPC-treated peat soil

TABLE 2. Compaction characteristics of OPC treated peat soils

OPC content, %	ρ_{dmax}, g/cm^3	w_{opt}, %
0	0.61	63
10	0.62	70
20	0.65	64
40	0.69	62

respectively. As the OPC contents were increased, the ρ_{dmax} values also increased up to 0.69 g/cm^3 and the value of w_{opt}, showed apparent increased to 70% (10% OPC) before w_{opt} dropped to 62% at 40% of OPC content. The amount of OPC used in treated peat soil resulted with a significant change in the shape of the compaction curves (Figure 4). The more OPC contents is added, the flatter the curvature of the compaction curves. This can be explained by the presence of increasing amount of OPC contents subsequently causing the soil to be less sensitive to water content towards the maximum dry density. Similar compaction behaviour was also presented by Boobathiraja et al. (2014) and Huat et al. (2005) in investigating the peat soils that were treated with cement and lime.

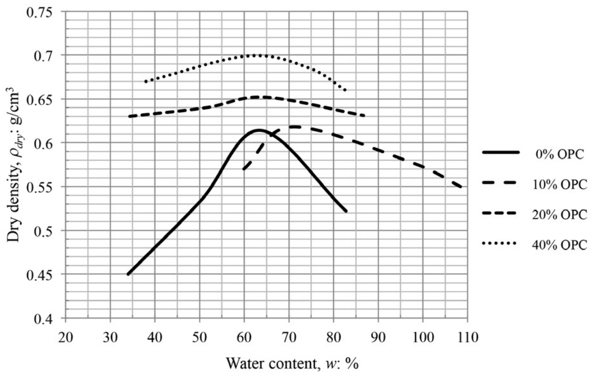


FIGURE 4. Compaction of untreated and OPC-treated peat soil

Axelsson et al. (2002) stated that density of peat soil tends to increase on stabilization since some of water in the soil is replaced by the stabilizer. Higher value of ρ_{dmax} for the treated peat soil compared to that of the untreated soil can be attributed to development of inter-particle bondings, created through the pozzolanic activity of OPC (Deboucha & Hashim 2010). The reaction of pozzolanic activity subsequently reduces the amount of inter-particle voids which ends up with a denser material (Figure 2(b)). Therefore, pozzolanic reaction that occured in the treated peat soil generally required lesser water to achieve maximum density if compared to that of untreated peat soil.

EFFECT ON PERMEABILITY

A series of falling permeability tests on untreated and treated peat soils were carried and out and the results are shown in Figure 5. The influence of curing periods of three and seven days of treated peat soils are presented in Table 3. In untreated state, the coefficient of permeability, k of the peat soil was 1.73×10^{-5} m/s. After treatment of peat soil with 10% of OPC and cured for three days, the k value was decreased to 6.60×10^{-5} m/s. Further treatment of peat soil with 20 and 40% of OPC decreased the k values to 1.87×10^{-6} m/s and 9.33×10^{-5} m/s, respectively (Table 3). The effect of curing period clearly seen as treated peat soil cured at seven days showed lower k values than that of treated samples cured at three days. The reductions in k value of treated samples cured at seven days were higher if compared with the samples cured at three days. Therefore, as seen in Figure 5, the k curve for treated sample cured at seven days was lower than that of samples cured at three days. A significant reduction in k value for treated sample cured at seven days can be seen at 10% of OPC content. At 40% of OPC content, the k value achieves its lowest value of 8.33×10^{-8} m/s (Table 3). The gradient of the curve became smaller in both curing periods, indicating that the rate of reduction in k value dropped as the amount of added OPC were increased. The results of the tests suggested that the optimum amount of OPC used to reduce k values of treated peat soils are 20% and 10% for three and seven days, respectively.

TABLE 3. Permeability of treated peat soils at two curing periods

OPC content, %	Coeff. of permeability, k, m/s	
	3 days	7 days
0	1.73×10^{-5}	1.72×10^{-5}
10	6.60×10^{-6}	4.92×10^{-7}
20	1.87×10^{-6}	1.61×10^{-7}
40	9.33×10^{-7}	8.33×10^{-8}

Reduction in k value in the OPC-treated peat soil is contributed by the nature of cement that reacts with the presence of water to form cementious products that bridging between the particles and filling the void spaces within the peat soil. These primary cementious products are originated from the chemical reaction of calcium silicates and calcium aluminates with water known as calcium silicate hydrates (CSH) and ettringite (CASH gels) and calcium hydroxide ($Ca(OH)_2$) (Wong et al. 2008). Thus, such filling of the soil inter-particles spaces has attributed to the reduction in k value of the treated peat soil. Moreover, Bergado (1996) described that further pozzolanic activity can also reduce the permeability and enhance the shear strength of stabilized soft soil if the curing time is extended. It is expected that a further reduction in permeability will also be expected for the treated peat soil if the curing period is extended, however, there is no data to support the fact since curing periods were limited to three and seven days.

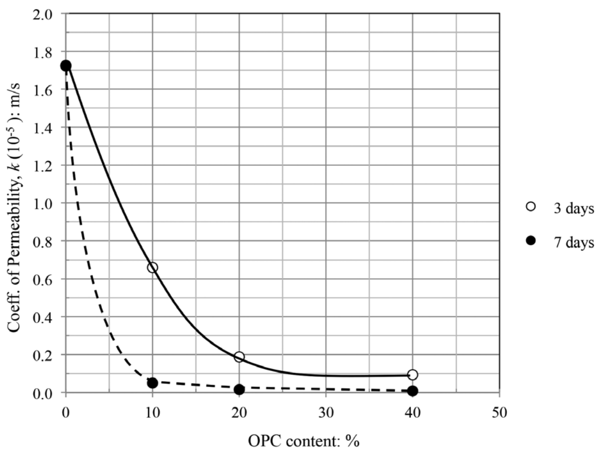


FIGURE 5. Results of permeability test of untreated and OPC-treated peat soil at two differents curing periods

EFFECT ON UNCONFINED COMPRESSIVE STRENGTH

The effect of cement treatment and curing periods on UCS were examined. Table 4 and Figure 6 show the results of the UCS tests for untreated and OPC-treated peat soils.

TABLE 4. Summary of the UCS tests of treated peat soils at two curing periods

OPC content, %	Unconfined compressive strength, q_u, kPa			
	3 days		28 days	
0	8.4		8.4	
10	17.0	103 %	32.4	286 %
20	30.0	256 %	50.0	493 %
40	61.0	627 %	98.2	1072 %

The effects of OPC content and curing are clearly exhibited as amounts of OPC contents were increased and the curing periods were extended from 3 to 28 days. However, the UCS values, q_u for treated peat soil cured at three days was lower than that of the samples cured at 28 days. The values of q_u for OPC-treated samples cured at three days ranged between 8.4 and 61 kPa. As OPC contents were increased from 10% to 20%, the treated samples cured at 28 days indicated by higher q_u values of 32.4 and 50 kPa, respectively. The UCS results for cured at 28 days showed that the q_u values apparently increased as the OPC contents were increased, as indicated by the slope of the linear line if compared to that of treated samples cured at 3 days. The increase in q_u values (in percentages) for treated peat soils with 10% OPC content, cured at 28 days was 286%. Meanwhile, for the treated samples cured at 3 days with a similar amount of OPC content, the increase in q_u only represented by approximately 103%. The influence of OPC contents on the q_u values are represented by strong coefficient of correlation as indicated by both samples treated at three and 28 days (Figure 6). This behaviour has been attributed by the formation of cementatious products as a result of pozzolanic reaction as stated earlier. Development of cementitious products of CSH that binded the soil particles resulted with the increase in the brittleness of treated soil hence, increase the unconfined compressive strength of peat soil. Sariosseiri and Muhunthan (2009) cited that treated soil with cement usually exhibit more brittle behaviour than untreated soils. The effect of cement content and curing period on unconfined compressive strength were also reported by Deboucha et al. (2008), Huat et al. (2005), Islam and Hashim (2010) and Wong et al. (2008). A comparative study on the application of different binders found that UCS strength of peat soil treated with OPC indicated by significant increase compared to that of treated with fly ash and quick lime (Aminur et al. 2009). Boobathiraja et al. (2014) also presented the improvement of the strength of peat soil that treated with OPC. The effect of curing period on the strength of the cement-treated peat soil was reported by Kalantari and Prasad (2014). Aminur et al. (2009) also found that the stabilised peat soil resulted with increasing strength as the curing periods were further extended from 7 to 28 days. These are the facts that the OPC develops its strength as further curing times are permitted to the stabilized soils. The result from pozzolanic reaction and formation of CSH and enttrigite from OPC made the structures denser and contributed to strength development in soil stabilised (Tang et al. 2011).

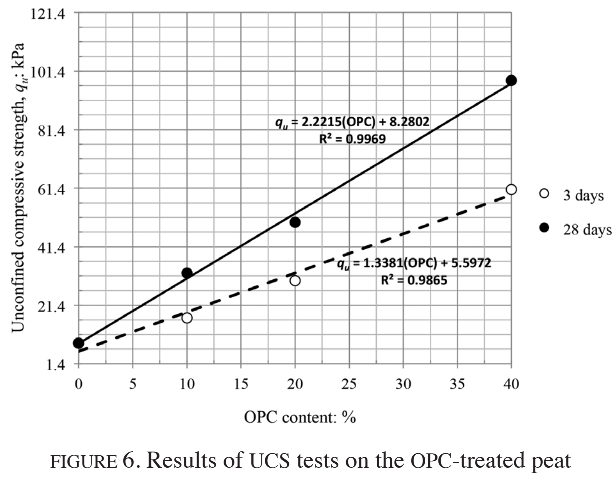


FIGURE 6. Results of UCS tests on the OPC-treated peat soil at two differents curing periods

CONCLUSION

The addition of ordinary Portland cement (OPC) on peat soil clearly modified the studied engineering characteristics. OPC-treated peat soil exhibited reduction in liquid limit and permeability values due to pozzolanic activity. The permeability values of treated samples are influenced by the contents of OPC and curing times. On the other hand, the compaction and UCS tests were indicated by the increase in maximum dry density and unconfined compressive strength. In addition of OPC content, the values of maximum dry density increased while slight decrease seen in the optimum moisture content. The amount of OPC used and duration of curing are significantly controlled the unconfined compressive strength. It is also found that as curing times were extended, the treated peat soil can apparently achieve higher strength.

ACKNOWLEDGEMENTS

The authors thank Universiti Kebangsaan Malaysia for supporting this research project under grant code UKM-GGPM-NBT-097-2010 and UKM-OUP-FST-2012. Special thanks are also due to the laboratory staff at the School of Environmental and Natural Resource Sciences, Faculty of Science and Technology, UKM for the assistance of sample preparation and soil testing.

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Received: 20 September 2013
Accepted: 28 March 2016