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Unconfined Compressive Strength of Cemented Peat

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Abstract: The aim of this paper is to evaluate the unconfined compressive strength of cemented peat in comparison to that of untreated peat. A laboratory study on the unconfined compressive strength of cemented peat is important in order to formulate a suitable and economical mix design for stabilized peat columns developed in deep peatland to support highway construction. To characterize the strength behavior of cemented peat, 14 test specimens of different mix designs of the cemented soil were prepared and tested in unconfined compression tests. The results revealed that test specimen with a mix design of 300 kg m^{-3} binder dosage by mass of wet peat (90 % MASCRETE and 10 % kaolinite in composition), 4 % calcium chloride by mass of binder, and 25 % siliceous sand by volume of wet peat gave the highest unconfined compressive strength of 413.0 kPa after 7 curing days in water. Such positive finding was largely attributed to the reactivity of the binder, calcium chloride and siliceous sand with wet peat. Thus, it can be concluded that high strength cemented peat can be produced when the MASCRETE and kaolinite stabilized peat admixture with siliceous sand acting as a filler, was activated by calcium chloride that accelerated the rate of cement hydration in the soil.

Key word: Cemented peat, unconfined compressive strength, mix design, binder

INTRODUCTION

Construction of highway on deep peatland without strong foundation often leads to excessive total and differential settlements of the highway. Consequently, it is disastrous to construct a highway on peatland without proper geotechnical site investigation in order to find the best solution to treat the soil. Widely found in lowland, peat is extremely problematic due to it's low shear strength and high compressibility. In practice, it is effective and economical to reinforce peatland with stabilized peat columns for highway construction purpose and the mix design of the columns is largely dependent on laboratory investigation of the cemented soil via unconfined compression tests.

Despite of the fact that many researches were done on cemented soils (Consoli *et al*., 2002; Tremblay *et al*., 2002; Rotta *et al*., 2003; Rao and Shivananda, 2005; Ahnberg, 2006) to enhance the understanding of their engineering behavior, the engineering characteristics of cemented peat are not completely understood. This is because the engineering properties of cemented peat are inadequately investigated due to the notion that it is difficult to stabilize peat because of the soil's high organic content. Furthermore, most data available on soil stabilization projects relate to the stabilization of soft clays with small amounts of organic matter (Hebib and Farrell, 2003). Recent advancement of cement chemistry and geotechnical engineering has seen the possibility of mixing chemical additives such as calcium chloride and rapid setting cement with wet peat to produce effective deep peat stabilization.

In view of that, laboratory mix design is important in order to formulate economical and suitable cemented peat with adequate strength for the application of stabilized peat columns on deep peatland. Since strength of cemented peat is largely measured by it's unconfined compressive strength due to the soil's low permeability and high stiffness, unconfined compression tests often provide relatively fast and cheap mean of determining the soil strength (Wong *et al*., 2008). As such, the study is concentrated at evaluating the unconfined compressive strength of peat stabilized by different binders, calcium chloride, sodium chloride and siliceous sand through laboratory testing investigation.

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MATERIALS AND METHODS

Peat:

Peat investigated in the study was sampled from Sri Nadi village, Klang in the state of Selangor, Malaysia. This research project was conducted from 1st May 2007 to 24th January 2009. Investigation on the basic properties of the soil revealed that the soil had high natural moisture content of 668.3 %, organic content of 96.0 %, specific gravity of 1.40, pH of 3.51 and fiber content of 90.0 %. Since the peat had more than 20 % fiber content, the soil can be classified as fibrous peat according to Dhowian and Edil (1980).

Binding Agents:

Five types of binding agents were used to stabilize the soil, namely Ordinary Portland cement, PHOENIX, WALCRETE, AVANCRETE and MASCRETE. While Ordinary Portland cement is produced from grinding clinker manufactured in a rotary kiln as a result of burning a mixture of limestone and clay at a temperature of 1400 °C, WALCRETE, PHOENIX, AVANCRETE and MASCRETE are specifically manufactured cements by Lafarge Malayan Cement Berhad for various concrete technology applications in building construction. WALCRETE is a masonry cement produced by blending a specific mixture of Portland cement, plasticizing material and air entraining agent. PHOENIX is a Portland composite cement derived from grinding and mixing calcium sulphate as a setting regulator with Portland cement clinker and other carefully selected secondary pozzolanic material such as fly ash. Regarded as a premium composite cement, AVANCRETE is produced at high fineness and workability with the inclusion of a superplasticizer as cement dispersant. MASCRETE is a rapid setting pulverized fuel ash cement formed with high fineness and by adding a superplasticizer as a cement dispersing agent.

Cement Accelerators:

Two types of cement accelerator were used to accelerate the hydration reaction of cement in the wet peat, namely, sodium chloride and calcium chloride. Cement acceleration means a speed up in the rate of cement reaction from chemical sense, an increase in the initial and final setting time of cement from physical aspect, and an increase in the rate of strength gain in a mechanical sense. Practically, the cement accelerators were used to reduce the curing period required for the cemented peat to achieve a high unconfined compressive strength. In other words, they actually accelerated the hardening process of the cemented peat within a reasonable short period of time.

Secondary Pozzolanic Materials:

Small amount of secondary pozzolanic materials were added to the cemented peat to promote secondary pozzolanic reactions which are responsible for the long term strength gain of the cemented soil. To evaluate the effect of the materials, three types of secondary pozzolanic materials were added to the cemented peat. They are ground granulated blast furnace slag, sodium bentonite and kaolinite. While ground granulated blast furnace slag is derived from the by product of iron manufacturing, sodium bentonite is formed by mixing sodium with bentonite, which forms from the weathering of volcanic ash in the presence of water. Kaolinite is a natural soil pozzolan that according to Deer *et al*. (1992), the soil is a layered silica mineral, with one tetrahedral sheet linked through oxygen atoms to one octahedral sheet of alumina octahedra.

Filler:

Well graded siliceous sand was used as a filler to increase the amount of solid particles in wet peat for the binder to unite and form cementation bonds. Practically, the filler yielded insignificant chemical reactions in cement hydrolysis due to the large sizes of the sand grains but it enhanced the strength of the cemented peat by increasing the contact areas for the cementation bonds to form, thereby producing a load sustainable stabilized soil structure. In addition, the filler reduced void ratio of cemented peat by filling the void spaces within the loose peat during the cementation process of the soil. Economically, it is feasible to reduce the cost of peat stabilization by including the filler into the cemented peat.

Preparation of Test Specimens:

14 test specimens of cemented peat of varying mix designs were prepared and cured in water for 7 days before testing. Wet peat at natural moisture content of 668.3 % was sieved such that the soil passed through 2 mm sieve size. The purpose of sieving the wet peat was to remove coarse materials such as roots, stones and large fibers greater than 2 mm size such that only homogenous wet peat was used for mixing to ensure

consistency of the soil's strength testing. For each test specimen, the sieved wet peat was initially mixed with a kitchen mixer to ensure that moisture was uniformly distributed throughout the soil before it was mixed with the binder, cement accelerator and siliceous sand for 10 min. Later, the cemented peat admixture was filled and tamped by hand in 4 layers up to 180 mm height in a plastic tube of 50 mm internal diameter and 250 mm height. Arrangement of each plastic tube was done vertically in a rack, which was later submerged under water in a water tank. After that, the test specimen was allowed to cure in the water under a pressure of 100 kPa. A dosage of 300 kg m^{-3} binder by mass of wet peat at natural moisture content of 668.3 % and 25 % siliceous sand by volume of the wet peat were added to the homogenized peat in the production of each test specimen without cement accelerator. In case of test specimens with cement accelerator, additional 4 % cement accelerator by mass of the binder was added to each test specimen's cemented peat admixture. After curing in water, an extruder was used to extrude each test specimen from the plastic tube before the specimen was trimmed to a height of 100 mm for testing. Table 1 specifies the various compositions of binder, cement accelerator and siliceous sand of all the test specimens.

Table 1: The various compositions of binder and cement accelerator of cemented peat specimens, each at a binder dosage of 300 kg m^{-3} by mass of wet peat at natural moisture content of 668.3 % and 25 % siliceous sand by volume of wet peat in unconfined compression tests

Soil specimen number	Composition of soil specimen
1	75 % OPC: 25 % GGBS (4 % CC by weight of binder)
2	80 % OPC: 10 % GGBS: 10 % SB (4 % CC by weight of binder)
3	85% OPC: 15% SB (4 % CC by weight of binder)
4	90 % PHOENIX: 10 % SB
5	90 % WALCRETE: 10 % SB
6	90 % AVANCRETE: 10 % K
7	90 % AVANCRETE: 10 % SB
8	90 % MASCRETE: 10 % K
9	90 % MASCRETE: 10 % SB
10	90 % AVANCRETE: 10 % K (4 % CC by weight of binder)
11	90 % AVANCRETE: 10 % SB (4 % CC by weight of binder)
12	100 % MASCRETE (4 % CC by weight of binder)
13	90 % MASCRETE: 10 % K (4 % SC by weight of binder)
14	90 % MASCRETE: 10 % K (4 % CC by weight of binder)

OPC = Ordinary Portland Cement; GGBS = Ground Granulated Blast Furnace Slag; SB = Sodium Bentonite; K = Kaolinite; SC = Sodium Chloride; CC = Calcium Chloride (Dosage of siliceous sand for a stabilized peat specimen is 25 % by volume of peat at 668.3 % moisture content)

Method of Experimentation:

All the test specimens were subjected to unconfined compression tests in order to determine their unconfined compressive strength. Procedures of the tests were carried out in accordance to U.S. ASTM standard (Head, 1982). Unconfined compression test is quite similar to the usual determination of compressive strength of concrete, where crushing a concrete cylinder is carried out solely by measured increases in end loading (Liu and Evett, 2004). In unconfined compression test, each test specimen was placed in unconfined compression machine and an axial loading was applied vertically using a 4.5 kN load frame as shown in Fig. 1. The loading is applied quickly so that the pore water cannot drain from the soil; the sample is sheared at constant volume (Budhu, 2000). The test specimen was subjected to a constant axial rate of strain of 1.5 mm min^{-1} at zero confining pressure. This rate is so rapid relative to the drainage of the specimen that there is no time for significant volume change in spite of the absence of a membrane to seal the specimen (Terzaghi *et al*., 1996). The largest value of the load per unit area or the load per unit area of 15 % axial strain, whichever occurs first, is known as the unconfined compressive strength (Liu and Evett, 2004).

RESULTS AND DISCUSSIONS

Results:

The relationship between unconfined compressive stress and axial strain of Ordinary Portland cement and calcium chloride based cemented peat at various binder compositions is shown in Fig. 2. It is evident in Fig. 2 that at a binder dosage of 300 kg m^{-3} by mass of wet peat and 25 % siliceous sand by volume of wet peat, test specimens with compositions of 75 % OPC: 25 % GGBS: 4 % CC, 80 % OPC: 10 % GGBS: 10 % SB: 4 % CC and 85 % OPC: 15 % SB: 4 % CC showed insignificant improvement in unconfined compressive strength when the strength for the compositions were found to be 37.5, 32.5 and 37.4 kPa respectively. The strength values were slightly higher than that of untreated Klang peat which was found to be 17.0 kPa by Wong *et al*. (2008).

Fig. 1: Unconfined compression test using 4.5 kN ELE proving ring

Fig. 3 illustrates the unconfined compressive stress-axial strain relationship of cemented peat specimens of PHOENIX, WALCRETE, AVANCRETE and MASCRETE based binders, each at a binder dosage of 300 kg m^{-3} by mass of wet peat and 25 % siliceous sand by volume of wet peat without cement accelerator. While the unconfined compressive strength of test specimens of binder compositions of 90 % PHOENIX: 10 % SB and 90 % WALCRETE: 10 % SB were found to be 31.4 and 28.9 kPa respectively, which were relatively low, the strength of test specimens with binder compositions of 90 % AVANCRETE: 10 % SB and 90 % MASCRETE: 10 % SB were discovered to be moderately high at 81.8 and 57.0 kPa respectively. High unconfined compressive strength in Fig. 3 was achieved for test specimens with binder compositions of 90 % AVANCRETE: 10 % K and 90 % MASCRETE: 10 % K when both strength were found to be 179.2 and 147.0 kPa respectively.

The relationship between unconfined compressive strength and axial strain of test specimens with different combinations of AVANCRETE, MASCRETE, kaolinite, sodium bentonite, sodium chloride and calcium chloride with siliceous sand acting as a filler is illustrated in Fig. 4. All test specimens with binder compositions in Fig. 4 yielded significantly higher unconfined compressive strength when compared to those of Figures 2 and 3. At a binder dosage of 300 kg m^{-3} by mass of wet peat and 25 % siliceous sand by volume of wet peat, test specimen with a binder composition of 90 % MASCRETE: 10 % K: 4 % CC yielded the highest unconfined compressive strength of 413.0 kPa. This was followed by test specimens with binder compositions of 90 % AVANCRETE: 10 % K: 4 % CC, 100 % MASCRETE: 4 % SC, 90 % AVANCRETE: 10 % SB: 4 % SC and 90 % MASCRETE: 10 % K: 4 % SC with their respective strength reached 375.5, 360.0, 343.3 and 260.6 kPa respectively.

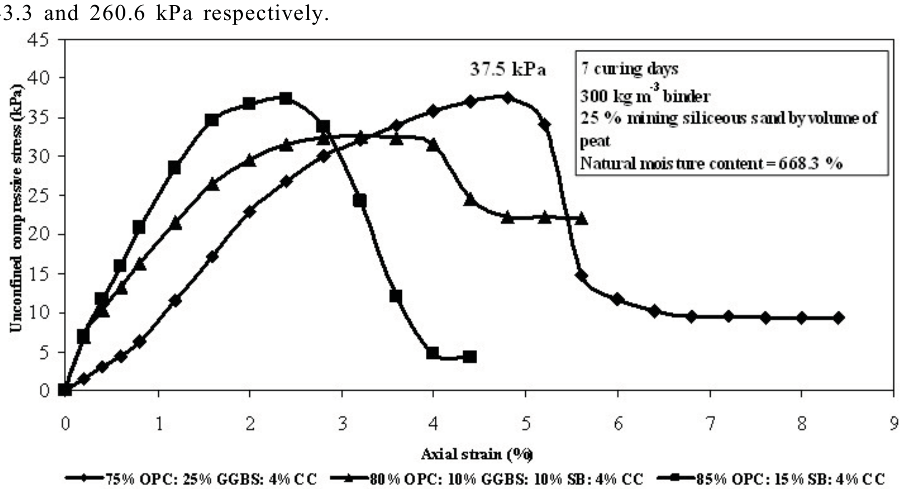

Fig. 2: Relationship between unconfined compressive stress and axial strain of cemented peat specimens of Ordinary Portland cement based binders, each at a binder dosage of 300 kg m^{-3} by mass of wet peat and 25 % siliceous sand by volume of wet peat with calcium chloride as a cement accelerator

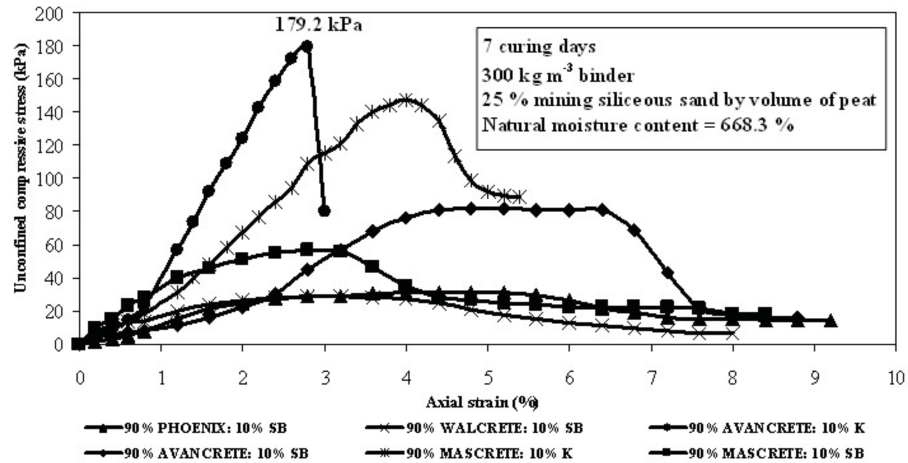

Fig. 3: Relationship between unconfined compressive stress and axial strain of cemented peat specimens of PHOENIX, WALCRETE, AVANCRETE and MASCRETE based binders, each at a binder dosage of 300 kg m^{-3} by mass of wet peat and 25 % siliceous sand by volume of wet peat without cement accelerator

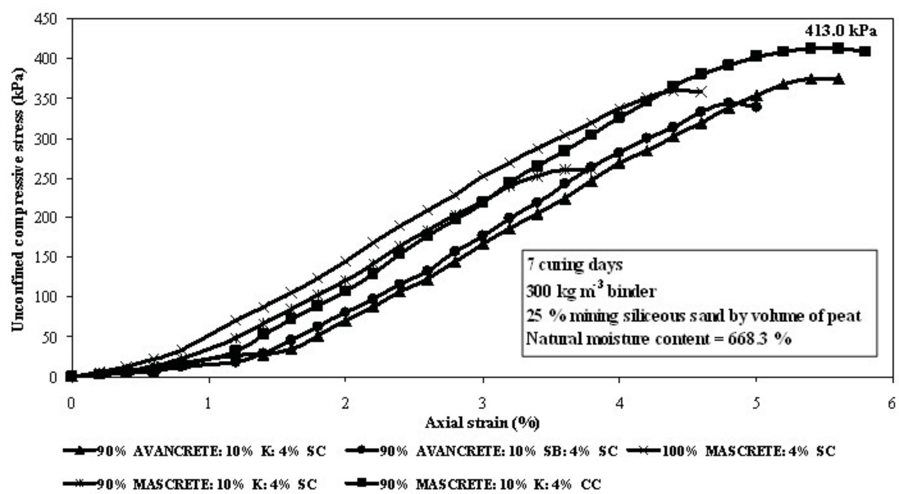

Fig. 4: Relationship between unconfined compressive stress and axial strain of cemented peat specimens of AVANCRETE and MASCRETE based binders, each at a binder dosage of 300 kg m^{-3} by mass of wet peat and 25 % siliceous sand by volume of wet peat with sodium chloride or calcium chloride as a cement accelerator

While stiffness modulus of the binder compositions sharply increased to 10226.7, 9891.5, 9678.3, 10714.3 and 10508.0 kPa respectively, their respective axial strain at failure were found to be 5.6, 5.4, 4.4, 4.8 and 3.6 %. The stiffness parameter values of the test specimens clearly differ much in comparison to those of untreated Klang peat. The secant stiffness and tangent stiffness of untreated Klang peat were found to be 205 and 51 kPa respectively, which were relatively low. Untreated Klang peat also exhibited higher axial strain at failure of 8.0 % when compared to those of cemented peat specimens in Fig. 4.

Discussion:

Effect of Ordinary Portland Cement Based Binders and Calcium Chloride on the Unconfined Compressive Strength of Cemented Peat Having Siliceous Sand as a Filler:

As illustrated in Fig. 2, the insignificant early strength gain of the cemented peat in comparison to that of untreated one indicated that Ordinary Portland cement in the binders failed to induce cement hydration in the wet peat to produce the required cementitious products that bond the peat and siliceous sand together to form hard cemented peat even with the presence of calcium chloride as a cement accelerator. The high natural moisture content of peat and water remaining trapped in the cement particle agglomerations after mixing were the main retarding factors of cement hydration in the peat. Besides, the black humic acid, a component of organic matter in peat tends to react with calcium liberated from cement hydrolysis to form insoluble calcium humic acid making it difficult for calcium crystallization, which is responsible for the increase of cemented soil strength to take place (Chen and Wang, 2006).

Influence of Binders Based on PHOENIX, WALCRETE, AVANCRETE and MASCRETE on the Unconfined Conpressive Strength of Cemented Peat with Siliceous Sand as a Filler:

It is evident in Fig. 3 that test specimens with AVANCRETE and MASCRETE based binders yielded significantly higher unconfined compressive strength when compared to those with PHOENIX and WALCRETE based binders and those with Ordinary Portland cement based binders in Fig. 2. It is also proven in Fig. 3 that kaolinite is a better pozzolan than sodium bentonite to react with AVANCRETE and MASCRETE to produce high strength cemented peat. This is because kaolinite has greater fineness than sodium bentonite.

The positive effect of AVANCRETE and MASCRETE based binders on the unconfined compressive strength of cemented peat was largely attributed to the inclusion of small amount of superplasticizer in the rapid setting cements. After mixing, the superplasticizer acted as cement dispersant and water reducer in the wet peat while improving the workability of the cemented peat admixture. The high natural moisture content of the peat was greatly reduced by the superplasticizer induced rapid setting cements without affecting the workability of the cemented peat admixture. In other words, the superplasticizer actually softened the cemented peat admixture to improve it's workability before the admixture hardened after curing in water. With the abrupt reduction in moisture content of peat after mixing with the binders and siliceous sand, high strength cemented peat can be produced with low water to cement ratio in the cemented peat admixture.

Impact of Cement Accelerators on the Unconfined Compressive Strength on the Cementation of the Peat by AVANCRETE, MASCRETE, Kaolinite and Sodium Bentonite with Siliceous Sand as a Filler:

In contrast to the strength of test specimens in Figures 2 and 3, the high unconfined compressive strength performance of test specimens of all the binder compositions in Fig. 4 was mainly due to the inclusion of cement accelerators in the form of sodium chloride and calcium chloride in addition to the positive reacting superplasticizer enhanced rapid setting cements in the wet peat. The cement accelerators actually increased the rate of cement hydration, thereby speeding up the initial and final setting time of the cement and contributed to the development of early strength of the test specimens. All the test specimens in Fig. 4 exhibited high stiffness and experienced short axial strain at failure. This corresponded to the brittle behavior of the specimens as the stiffer a specimen was, the shorter was its corresponding vertical strain at failure and the higher the specimen unconfined compressive strength (Wong *et al*., 2008). The highest unconfined compressive strength achieved by the test specimen at a binder composition of 90 % MASCRETE: 10 % K: 4 % CC indicated that kaolinite can be a good pozzolan for MASCRETE to chemically react with wet peat, siliceous sand and calcium chloride to produce rapid hardening cemented peat. The result also showed that calcium chloride is a better cement accelerator than sodium chloride to accelerate cement hydration process in cemented peat admixture.

Conclusion:

From the laboratory testing investigation on unconfined compressive strength of cemented peat, the following concluding remarks are drawn.

Test specimens with Ordinary Portland cement based binders, siliceous sand and calcium chloride did not show significant improvement in unconfined compressive strength after 7 curing days in water. This was largely due to the peat's high natural moisture content and highly acidic nature of organic matter in the soil, making it difficult to be stabilized by Ordinary Portland cement based binders even with the presence of pozzolan and calcium chloride.

Inclusion of 4 % calcium chloride by mass of binder into the wet peat with MASCRETE and kaolinite as binder at a dosage of 300 kg m^{-3} by mass of wet peat and 25 % siliceous sand by volume of wet peat yielded test specimen with the highest unconfined compressive strength among all the test specimens tested. This was mainly due to the function of calcium chloride as a cement accelerator that increased the rate of cement hydration in the wet peat and the role of superplasticizer as cement dispersant in the wet peat that improved the workability and lowered the water to cement ratio in the cemented peat admixture, thereby solidified the test specimen within 7 curing days in water.

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