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Strength and Permeability of Stabilized Peat Soil

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Abstract: The aim of this study was to analyze the unconfined compressive strength and initial permeability of peat soil stabilized by a mixture of Ordinary Portland cement, ground granulated blast furnace slag and siliceous sand. An understanding of the stabilized soil properties is of great importance for the design of deep stabilization in peat land for highway construction. Significant evidence on the positive effects of the admixture at stabilizing peat soil was discovered from laboratory testing investigation of the study. Results from the investigation indicated that addition of the admixture was able to increase unconfined compressive strength and reduce initial permeability of the stabilized soil as compared to those of untreated peat.

Key words: Ordinary portland cement, ground granulated blast furnace slag, siliceous sand, peat

INTRODUCTION

Problematic deep peat exhibits high compressibility, medium to low permeability, low strength and volume instability. Consequently, it is regarded as the worst foundation soil for supporting man-made structures. Under such circumstances, deep soil stabilization technique is often an economically attractive alternative to removal of deep peat or use of piles as deep foundation. The essential feature of deep soil stabilization is that columns of stabilized material are formed by mixing the soil in place with a 'binder' and the interaction of the binder with the soft soil leads to a material which has better engineering properties than the original soil (Hebib and Farrell, 2003).

It is generally recognized that organic matter and low pH of peat in the presence of black humic acid tend to interfere the hydration process if it is to be stabilized by Ordinary Portland cement. This is possible due to the fact that the acid 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 cement soil strength to take place (Chen and Wang, 2006). Furthermore, the secondary pozzolanic reaction of the cement stabilized peat is retarded due to insufficient silica (SiO_2) and alumina (Al_2O_3) that can react with calcium hydroxide [$(Ca(OH)_2$] generated from cement hydration to form secondary calcium silicates and aluminates, which are responsible for the long term strength gain of the stabilized peat soil.

It is evident from research that engineering properties of peat can be improved with the inclusion of Portland cement and ground granulated blast furnace slag (a by product of iron manufacturing) with siliceous sand acting as filler. When mixed with cement in the soil, the slag which contains silica, alumina and reactive lime is activated and this can accelerate the reactions of cement in peat and improves the stabilization effect. Siliceous sand can be used as filler to increase the number of solid particles in peat soil. Basically, inclusion of the filler produces no chemical reaction but it enhances the strength of the stabilized peat by increasing the number of soil particles available for the binders to unite and form a load sustainable stabilized soil structure. Furthermore, the filler helps to reduce the void ratio of the soil by filling the void spaces within the soil during stabilization. As such, the research focused on the study of the effect of cement, slag and well graded siliceous sand at stabilizing peat soil by investigating the peak unconfined compressive stress, undrained shear strength development and reduction of permeability of stabilized peat with increasing curing time for deep peat stabilization through laboratory mix design and testing investigation.

MATERIALS AND METHODS

Soil sampling: For laboratory investigation, peat soil was sampled from a site in Sri Nadi village, Klang, Selangor Darul Ehsan, Malaysia. This research project was conducted from 1st May 2007 to 28th February 2008. Trial pits were excavated to a depth of 1 m below the ground surface in order to obtain both undisturbed and disturbed soil samples below the ground water table. Close examination of each trial pit indicated that the ground water table was about 0.3 m from the ground surface. This

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Table 1: Basic properties of Klang peat

Basic peat soil property	Range	Average
Initial void ratio	8.0-9.6	9.30
Specific gravity	1.23-1.48	1.40
Bulk density (kg m^{-3})	1036-1040	1038.00
pH of peat	-	3.51
pH of ground water	-	4.07
Natural moisture content (%)	573.0-691.0	668.30
Organic content (%)	88.6-99.1	96.50
Ash content (%)	0.9-11.4	3.60
Fiber content (%)	90.3-90.5	90.40

showed that the peat had a very high water holding capacity. Visual observation on the peat indicated that the soil was dark brown in colour. When the soil was extruded on squeezing (passing between fingers), it could be observed that the soil was somewhat pasty with muddy water squeezed out and the plant structure was not easily identified. Based on the visual observation, the soil can be classified as H_4 according to von Post System based on its degree of humification. Some basic properties of the peat soil are shown in Table 1.

Preparation of stabilized soil specimens: Stabilized soil specimen preparation, mixing and curing procedures adopted in the research are based on the Design Guide of Soft Soil Stabilization which was prepared as part of the European Soil Stabilization (EuroSoilStab) projects (Hebib and Farrell, 2003). According to Hebib and Farrell (2003) the design guide covers the different methods of stabilizing soft organic soils, the design approaches that are normally adopted, the tests methods to determine the appropriate binder and the site equipment and installation procedure to be used. In accordance with the design guide, isolated roots and coarse material were removed from wet peat at its natural state before it was initially mixed with a mixer for homogenization. The wet soil was later mixed with cement, slag and well graded siliceous sand for 10 min before placing it in plastic tubes of 50 mm in internal diameter and 248 mm in height, arranged vertically into the rack, submerged in water inside water tank and cured under a pressure of 9 kPa, which is equivalent to 0.5 m sand usually laid on top of the stabilized soil columns in the field immediately after the columns formation. The required dosage of binders and siliceous sand are given in kg m^{-3} relative to the wet mass of peat at its natural moisture content of 668.3%. After curing, specimens from the tubes were extruded for unconfined compression tests. Specimens for laboratory vane shear and falling head tests were prepared in the same manner with exception that they were placed and cured in steel moulds of sizes 151.8 mm internal diameter × 127 mm height and 104.2 mm internal diameter × 130 mm height respectively. The top of each mould was attached to extension collar of 60.3 mm height. After curing, the extension collar was removed and the specimen trimmed to the size of the mould before testing.

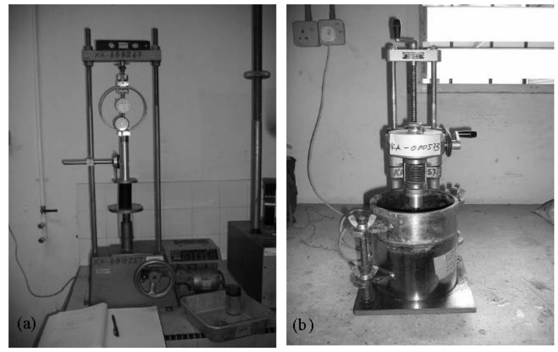

Fig. 1: Apparatus arrangement for (a) unconfined compression test (b) laboratory vane shear test

Laboratory mix design procedure: Laboratory testing investigation of the research was done in accordance to Manual of Soil Laboratory Testing (Head, 1994) based on British (BS1377: 1990) and US ASTM standards. The trend of the unconfined compressive strength gain of the stabilized peat soil was evaluated using unconfined compression tests according to different compositions and dosages of cement and slag at 950 kg m^{-3} well graded siliceous sand for 28 curing days. After curing, each plastic tube was removed from water tank, specimen extruded from the tube to a height of 100 mm and tested for unconfined compressive strength. The implication of well graded siliceous sand inclusion into the stabilized soil on the undrained shear strength gain of the soil was evaluated using standard laboratory vane shear apparatus. Each stabilized soil specimen for the test was cured for 7, 14 and 28 days before testing in order to investigate the trend of its undrained shear strength gain with curing time. The undrained shear strength of the stabilized peat specimens were also compared to that of undisturbed peat specimen. Comparison between the initial hydraulic conductivity of both untreated and stabilized peat (cured after 14 days) specimens were evaluated using standard falling head apparatus. Apparatus arrangement for unconfined compression and laboratory vane shear tests are shown in Fig. 1a and b, respectively.

RESULTS AND DISCUSSION

Unconfined compression tests: The 28 days unconfined compressive strength of stabilized peat specimens mixed with 950 kg m^{-3} siliceous sand at different compositions and dosages of cement and slag in comparison to that of undisturbed peat specimen can be observed in the soil stress-strain curves in Fig. 2. Observation on the figure indicated that basically, all of the stabilized peat specimens showed increment in their

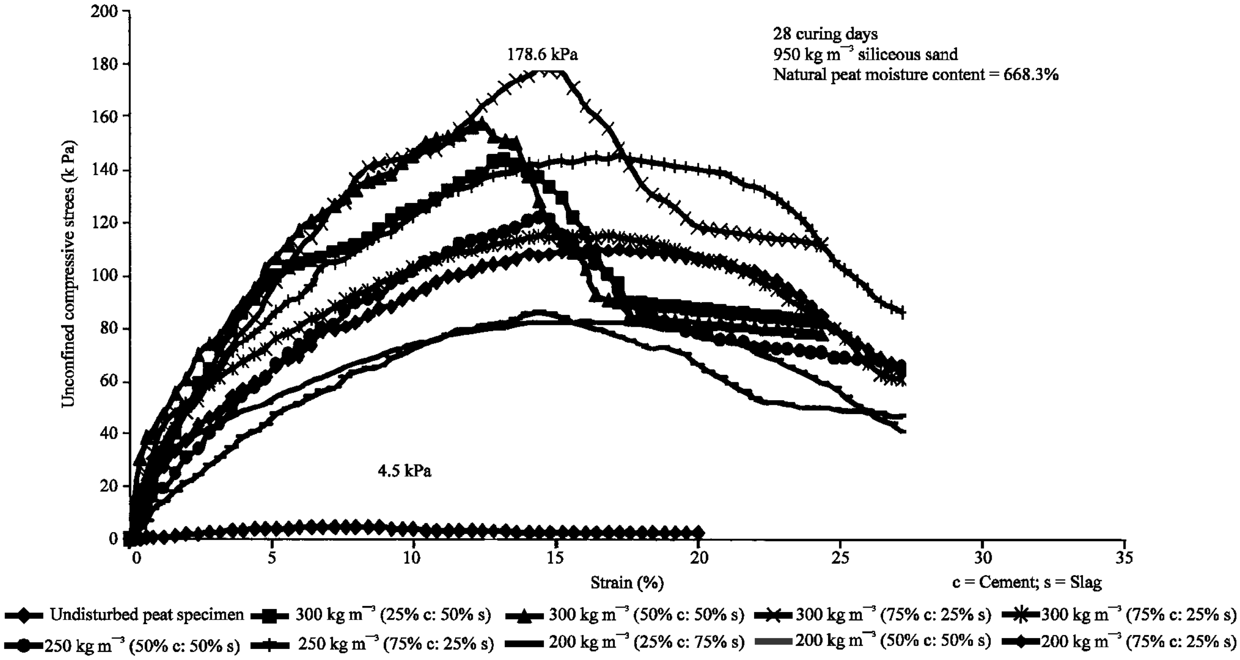

Fig. 2: Relationship between stress and strain of undisturbed and stabilized Klang peats in unconfined compression tests

unconfined compressive strength if compared to that of untreated peat specimen which was 4.5 kPa. However, the unconfined compressive strength gain of the stabilized peat specimen was only significant after a minimal dosage of 250 kg m^{-3} binder with 75% cement and 25% slag in composition was added. At the dosage and composition of the binder, its unconfined compressive strength reached 142.5 kPa and with the dosage of binder increased to 300 kg m^{-3}, the stabilized soil specimen yielded the highest unconfined compressive strength of 178.6 kPa as compared to those of other compositions and dosages of the stabilized soil specimens. The high dosage of the binders and siliceous sand required to stabilize the peat can be explained by the fact that the soil has a very low amount of solid particles to be stabilized and hence, more cement, slag and siliceous sand need to be added to the soil to form a sustainable load bearing stabilized soil.

For highly organic soils, sufficient binder must be added in order to achieve effective soil stabilization. This is because the soils require adequate binder for neutralization of its humic acid. That explains the finding that at 300 kg m^{-3} binder and 950 kg m^{-3} siliceous sand, a composition of 75% cement and 25% slag was sufficient at increasing the unconfined compressive strength of the soil as a result of adequate occurrence of hydration and secondary pozzolanic reactions after mixing due to neutralization of the acid.

Laboratory vane shear tests: Figure 3 shows the undrained shear strength development of stabilized peat

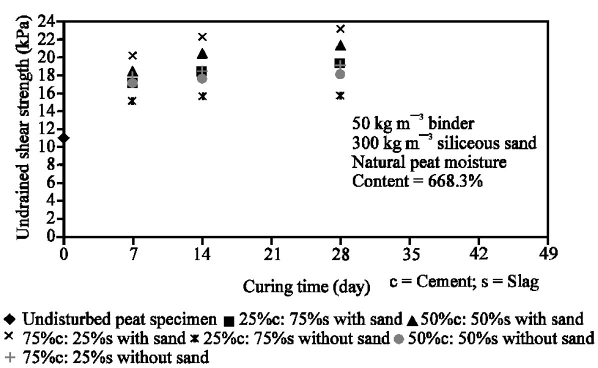

Fig. 3: Undrained shear strength development of the stabilized peat in different binder compositions with curing time

specimens over curing time at a binder dosage of 50 kg m^{-3} in varying compositions of cement and slag (25% cement: 75% slag, 50% cement: 50% slag, 75% cement: 25% slag) with and without siliceous sand. In general, the stabilized peat specimens of all compositions of cement and slag without siliceous sand did not show significant improvement in undrained shear strength after 28 curing days. The highest undrained shear strength of the stabilized peat was achieved with a composition of 75% cement and 25% slag at 19.0 kPa. With the inclusion of 300 kg m^{-3} siliceous sand, the stabilized peat specimens in all compositions of cement and slag showed slight increase in undrained shear strength over curing

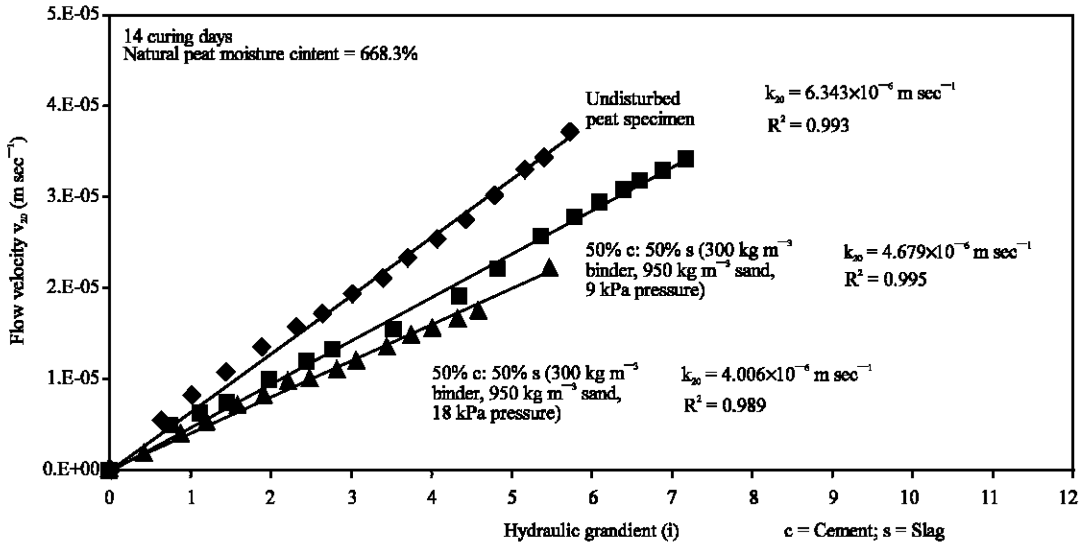

Fig. 4: Relationship between flow velocity, v_{20} and hydraulic gradient, i of undisturbed and stabilized Klang peats in falling head tests

time. A composition of 75% cement and 25% slag with siliceous sand yielded the most significant undrained shear strength development with the strength developed from 20.0 kPa after 7 curing days to 22.2 and 23.1 kPa after 14 and 28 curing days, respectively.

The finding implies that inclusion of siliceous sand enhances the undrained shear strength development of peat stabilized with cement and slag. Siliceous sand, being a chemically inert material does not take part in the hydration and secondary pozzolanic reactions but rather, acts as filler that effectively reducing the void ratio by filling up the void spaces within the stabilized peat. This produces a denser stabilized peat with higher undrained shear strength over increasing curing time if compared to that of stabilized peat without siliceous sand.

However, the low strength gain achieved by the stabilized soils from the tests indicated that addition of 50 kg m^{-3} binder was insufficient at stabilizing peat. The results point to the fact that when the black humic acid in peat is not neutralized by sufficient binder, the acid strongly retards the hydration and secondary pozzolanic reactions because it has a strong chemical affinity to calcium liberated from cement hydrolysis. Hence, where calcium is present in solution, humic acid may react with the calcium and form insoluble calcium humic acid and such a combination makes it difficult for the calcium crystallization, which is responsible for the increase of the cemented soil strength to take place (Chen and Wang, 2006).

Falling head tests: A comparison between the hydraulic conductivity of undisturbed and stabilized peat specimens using falling head tests is shown in Fig. 4. In its natural state, the coefficient of permeability of the peat was 6.343×10^{-6} m sec^{-1}, which was lowly permeable and comparable to that of very fine and silty sand. However, after the peat was stabilized with 300 kg m^{-3} binder (50% cement: 50% slag) and 950 kg m^{-3} siliceous sand under an initial pressure of 9 kPa at 14 curing days, its coefficient of permeability was reduced to 4.679×10^{-6} m sec^{-}.[1] At the same binder dosage and composition, siliceous sand quantity and curing time, the coefficient of permeability of the stabilized soil was further reduced to 4.006×10^{-6} m sec^{-1} under an initial pressure of 18 kPa. The reduction in the hydraulic conductivity in the stabilized peat in comparison to that of undisturbed peat is attributable to the chemical reactions between cement and slag with increasing curing time, filling of void spaces within the soil by siliceous sand and the initial pressure applied immediately after mixing the soil with the binder and siliceous sand.

The decrement of the soil permeability is due to the fact that when cement and slag are mixed with fully saturated peat soil, calcium silicates and calcium aluminates in the cement interact with water to produce major primary cementitious products known as calcium silicate hydrates and ettringite (CSH and CASH gels) and calcium hydroxide [$Ca(OH)_2$]. While CSH and CASH gels govern the primary bondage strength of the cemented soil, calcium hydroxide [$Ca(OH)_2$] is required to react with excess silica (SiO_2) and alumina (Al_2O_3) from the cement and slag under secondary pozzolanic reaction to form secondary calcium silicate and aluminate hydrates which fill in the pores within the soil thereby, creating its secondary bondage strength (Wong *et al*., 2008). Such blocking of the soil pores reduces the permeability and increases the strength gain of the soil. Inclusion of siliceous sand and increasing the initial pressure immediately after mixing further block the soil pores and consequently, the permeability of stabilized soil is further reduced with increasing curing time.

CONCLUSION

Based on the laboratory investigation on the effect of Ordinary Portland cement, ground granulated blast furnace slag and siliceous sand at stabilizing peat soil, the following conclusions are made:

The unconfined compressive strength of stabilized peat formed by mixing peat with cement, slag and siliceous sand was significantly higher than that of undisturbed peat.

Inclusion of siliceous sand into the cement-slag stabilized peat yielded higher undrained shear strength if compared to that without siliceous sand. However, if the black humic acid in peat is not neutralized by adequate binder, the acid tend to react with calcium hydroxide ($Ca(OH)_2$) liberated from cement hydrolysis which in turn retards the development of undrained shear strength of stabilized peat over increasing curing time.

The hydraulic conductivity of cement-slag stabilized peat with siliceous sand acting as filler after 14 days of curing under a pressure of 9 kPa was lower than that of undisturbed peat. At the same binder dosage, siliceous sand quantity and curing time, the stabilized peat cured under a pressure of 18 kPa yielded a further lower hydraulic conductivity.

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