Performance of Compacted and Stabilized Clay with Cement, Peat Ash and Silica Sand

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ABSTRACT

An experimental investigation was carried out to evaluate the performance of compacted clay stabilized with cement, peat ash and silica sand. A significant soil improvement can be achieved through the compaction and stabilization of clay. The main objective of this study is to evaluate shear strength characteristics, CBR and unconfined compression behavior of untreated and stabilized soil with cement, peat ash and silica sand. The soil specimens were tested at optimum moisture content and maximum dry density. Based on the results obtained from standard Proctor compaction test, the ideal mix design was further applied for direct shear, unconfined compression and CBR tests. Both untreated and stabilized soil specimens were subjected to 10.90 kPa, 21.80 kPa, 43.60 kPa and 87.20 kPa vertical effective stresses of direct shear tests. The microstructure analysis of the stabilized soil was examined using scanning electron microscope test. Results indicate that there is a significant influence of cement addition to the strength of the stabilized soil. It was found that the unconfined compressive strength of the stabilized soil specimen with 2% partial replacement of cement with peat ash is almost 1.7-fold greater than that of the untreated soil specimen. The type of failure behavior of the test specimens varied greatly. The untreated soil specimen exhibited ductile behavior in failure under unconfined compression test; whereas, stabilized soil specimen with the binder composition of cement 18%, peat ash 2% and silica sand 5% posed brittle behavior.

Highlights

► Peat ash dosage affected compaction properties of the soil specimen. ►Ordinary Portland cement was partially substituted with peat ash. ►Binder composition of cement 18%, peat ash 2% and silica sand 5% improved shear strength parameters, CBR and unconfined compressive strength of the soil specimen.

KEYWORDS: Clay, Cement, Peat ash, CBR, Unconfined compression, Direct shear.

INTRODUCTION

Peat is generally defined as a soil which has accumulated partially decomposed plant and animal residues under anaerobic conditions (Cayci et al., 2011). The peat investigated by Wong et al. (2013) was spongy in nature, very pasty, highly organic soil, of high water content and classified as a moderately highly decomposed peat. Therefore, from the civil engineering viewpoint, peat is a problematic type of soil with poor engineering properties. Besides, it is generally recognized that various ashes such as fly ash and biomass ash have the capability of partially

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replacing cement in civil engineering applications (Horpibulsuk et al., 2012). Similarly, peat ash could be used as partial cement replacement of stabilized clay in order to reduce the cement addition on input. For the purpose of this study, peat ash was obtained by heating peat at a temperature of 440°C in a muffle furnace (ASTM D 2974). Although cement is one of the oldest building materials around, it is produced at a very high temperature of about 1500°C in order to make it possible for the clinker to form. The main concern of cement production is highly energy-intensive process and greenhouse gas emission involving environmental damage with respect to carbon dioxide (CO_2) production (Mahasenan et al., 2003). Therefore, utilization of peat ash to stabilize fine grained soils and partial replacement of cement with peat ash can reduce the use of cement in the stabilized soil and offer an environmental advantage. Furthermore, construction of a highway on soft clay is problematic because of excessive total and differential settlements. Thus, stabilization of soft clay with cement would improve soil properties and limit the settlement. Since, during the stabilization process, plasticity of soil will be reduced, it becomes more workable, and desired engineering characteristics of soil such as shear strength, unconfined compressive strength and load bearing capacity will be improved (Hossain and Mol, 2011). On the other hand, most of the structures include a significant part of soil under their footings that evaluates the strength of this part is consequential. Different items such as type of cement, stabilizing agent, physical properties of soil, testing method and moisture content of soil can be affected on stabilized soil (Yilmaz and Ozaydin, 2013). Stabilization of clay with cement has been extensively researched by Terashi et al. (1979), Kawasaki et al. (1981), Clough et al. (1981), Kamon and Bergado (1992), Uddin (1994), Yin and Lai (1998), Consoli et al. (2000), Kasama et al. (2000) and Cocka and Tilgen (2010). Based on the research conducted by Yilmaz and Ozaydin (2013), increased cement content in soil specimen under unconfined compression test has changed failure pattern of the soil specimen from ductile to brittle. According to Croft (1967), soil compositions can contribute to achieve good stabilization, and stabilizers such as cement would have certain influences on the physical properties of stabilized soil. Based on another study that was executed by Croft (1968), suitability of stabilized soil with cement was investigated in terms of the effect of texture as well as chemical and mineralogical compositions of soil. Based on a research by Horpibulsuk et al. (2010), stabilization with cement can be stated as cement products fill the pore space and compaction would alter the soil into a dense state due to slipping of soil particles over each other and forming groups together. Besides, there are many investigations that fulfilled the improvement of clayey soil with sand by employing different techniques. According to Nazir and Azzam (2010), soft clays which exhibit poor strength, such as clay deposited in coastal areas, can be improved with sand. The bearing capacity of foundations on soft clay improve by locating a layer of granular filler with a limited thickness (Love et al., 1987). This paper aims to evaluate the California bearing ratio, shear strength and unconfined compressive strength of compacted and stabilized clay with cement, peat ash and silica sand. Several studies have already focused on stabilization of clay with cement and fly or biomass ashes (Horpibulsuk et al., 2012; Shenbaga et al., 1999; Sazzad et al., 2010). Despite such positive developments, the use of peat ash for clay stabilization was not completely investigated. In this paper, peat ash as a novel material with the novel usage of peat to stabilize cemented clay was explored. The expected output of this paper is an ideal mix design of compacted clay stabilized with cement, peat ash and silica sand that can be efficiently utilized to improve the ground of shallow clay for highway construction.

MATERIALS AND METHODS

Soil Sample Collection and Materials Used

In order to stabilize soil, clay was sampled at 2 meters depth of 10 excavated trial pits from Taman

Wetlands in Putrajaya area, in the state of Selangor in Malaysia (Fig. 1).

Figure (1): Site location of soft clay from Putrajaya

From initial investigation and observation, the soil was found light brown in color with some leaves and roots on the surface. Based on particle size analysis, the soil had 62% clay, 15% silt and 23% sand. From such analysis, the soil can be classified as silty sandy clay (Fig. 2). The basic properties of clay such as natural moisture content, specific gravity, organic content and pH were determined and found to be 45%, 2.46, 5.3% and 7.10, respectively. Moreover, peat was collected from Johan Setia village, Kampong, Klang, Selangor, Malaysia at about 30 cm depth of 8 trial pits. Sampled peat in initial observation was found very soft, with high compressibility, dark brown in color and contained much more organic matters such as roots and leaves. The peat found by Wong et al. (2013) had natural moisture content of 668%, organic content of 96%, fiber content of 90%, ash content of 4% and pH of 3.51. In order to convert peat to ash, peat sample was carried to the Laboratory and heated in a muffle furnace at a temperature of 440°C (ASTM D 2974). The type of cement used in this study is Ordinary Portland Cement (OPC) from YTL company. In addition, silica sand was collected at the Civil Engineering Laboratory, Universiti Tenaga Nasional (UNITEN).

Laboratory Mix Design

Table 1 summarizes the trial mix designs of stabilized clay with various percentages of cement, peat ash and silica sand. According to Table 1, a total of 5 sets of untreated and stabilized soil specimens were prepared to perform standard Proctor compaction test. In order to stabilize the clay with ordinary Portland cement, peat ash and silica sand, various proportions of cement 4.5-18%, peat ash 0.5-2% and silica sand 5% by dry weight of the soil were mechanically mixed with clay and compacted in three equal layers to achieve Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). On the basis of the partial replacement of cement with 2% peat ash, binder composition of cement 18%, peat ash 2% and silica sand 5% was chosen for the purpose of direct shear, CBR and unconfined compression tests.

Table 1. Trial mix designs of stabilized clay

Description	Clay (%)	Cement (%)	Peat ash (%)	Silica Sand (%)
Untreated clay	100	-	-	-
Partial replacement of cement with peat ash	90	4.5	0.5	5
	85	9.0	1.0	5
	80	13.5	1.5	5
	75	18.0	2.0	5

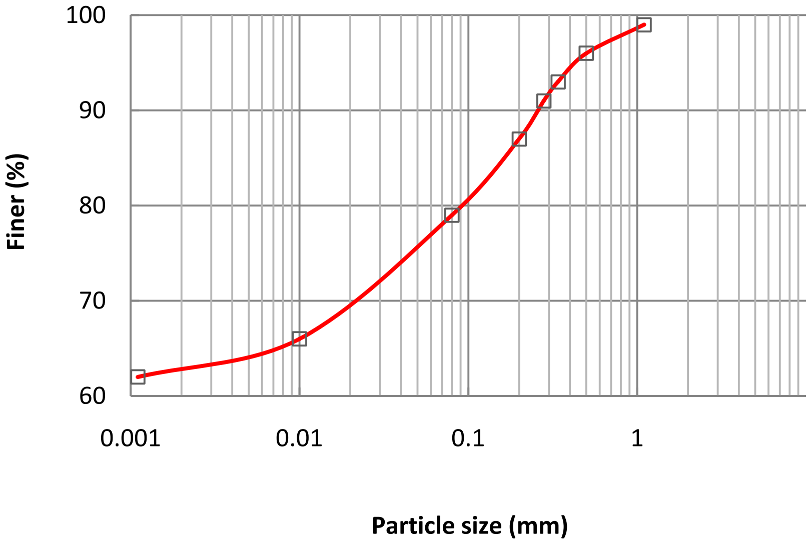


Figure (2): Particle size distribution curve of untreated soil

Standard Proctor compaction test was carried out on 5 test specimens (set of test specimens in Table 1) to establish compaction curves (Fig. 3). Based on Fig. 3, it can be seen that addition of stabilizers and compaction energy increased the compact ability of the soil specimen. Thus, the compacted soil specimen can control the strength and resistance of deformation. Comparison of the moisture content of the untreated and stabilized soil specimens indicates that the stabilized soil specimens were consistently attained on the wet side of the optimum moisture content from the compaction Proctor test.

Notes:

OPC = Ordinary Portland cement;
PA = Peat ash;
SS = Silica sand.

Test Setup

In order to quantify mechanical properties of both untreated and stabilized soil specimens, laboratory direct shear, unconfined compression and CBR tests were performed. To assess the effect of peat ash on shear strength, unconfined compressive strength and CBR value of untreated test specimen and ideal mix design of stabilized soil with the binder composition of cement 18%, peat ash 2% and silica sand 5% were tested. Direct shear, unconfined compression and CBR tests are based on the standards (ASTM D 2166), (ASTM D 3080) and (ASTM D 698), respectively. In addition, standard Proctor compaction test that was carried out to obtain maximum dry density and optimum moisture content was based on the ASTM D 698; organic content and pH tests were based on (ASTM D 2974) and (BS 1377: 1990), respectively.

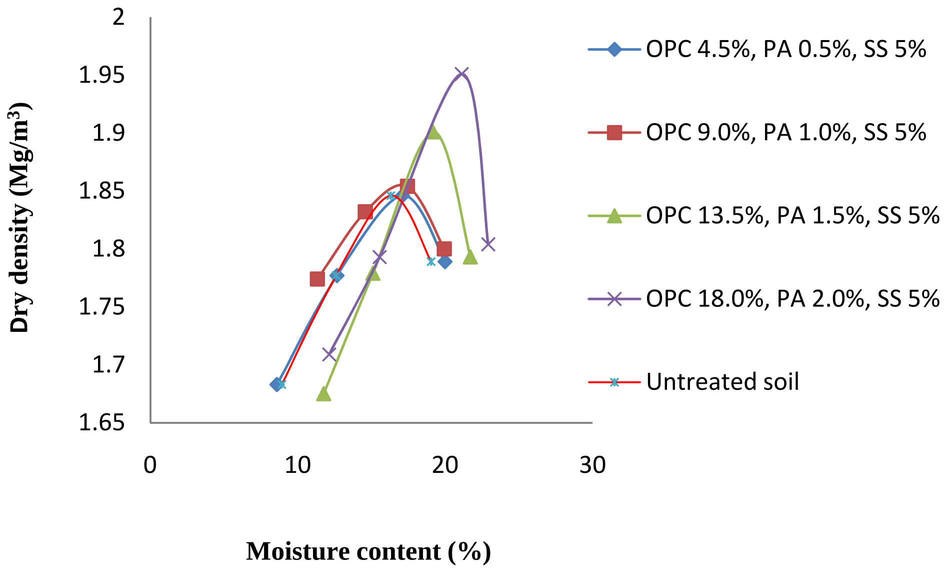


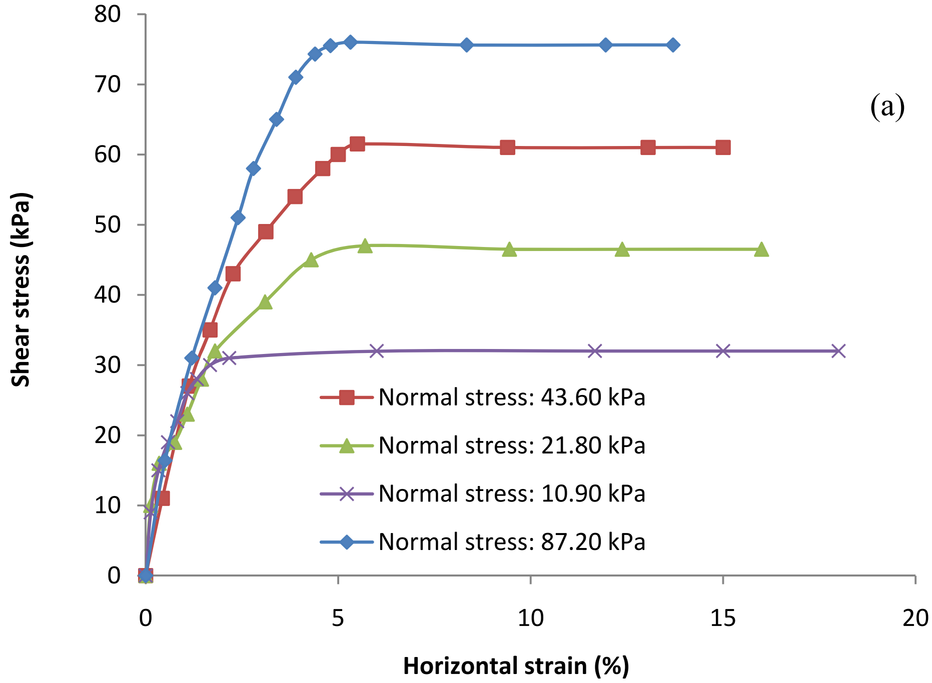
Figure (3): Effect of stabilization on dry density and moisture content of clay

Direct Shear Test

To perform the direct shear test, 2 sets of untreated and stabilized soil specimens were sheared in a 60 mm square shear box under 10.90 kPa, 21.80 kPa, 43.60 kPa and 87.20 kPa normal effective stresses. To supply shear box specimen, the oven dried soil was mixed with cement 18%, peat ash 2%, silica sand 5% and compacted at optimum moisture content and maximum dry density in a compaction mould. Then, specimen was taken out of the compaction mould using a hydraulic jack and a 60×60×30 mm^3 soil specimen was cut from cylindrical specimen using a jigsaw. Porous platens were positioned at the bottom and top of the specimen and assembled shear box was placed in direct shear apparatus with an applied shear rate of 0.5 mm/min and different normal stresses.

Unconfined Compression Test

The unconfined compression test was conducted to determine the values of unconfined compressive strength and axial strain of untreated and stabilized soil specimens as well as the behavior of cylindrical soil specimen in failure. As the direct shear test, oven dried soil was mixed with certain percentages of cement, peat ash and silica sand at optimum moisture content. A cylindrical mould with a diameter of 50 mm and a height of 91 mm was used to prepare both untreated and stabilized soil specimens. The inner surface of the mould was lightly lubricated and soil sample was compacted in three equal layers. To obtain the required height of specimen, the bottom and top of specimen were trimmed. The soil specimen was placed centrally on the bottom platen of apparatus. The unconfined compression test was performed as soon as the test specimen was prepared.



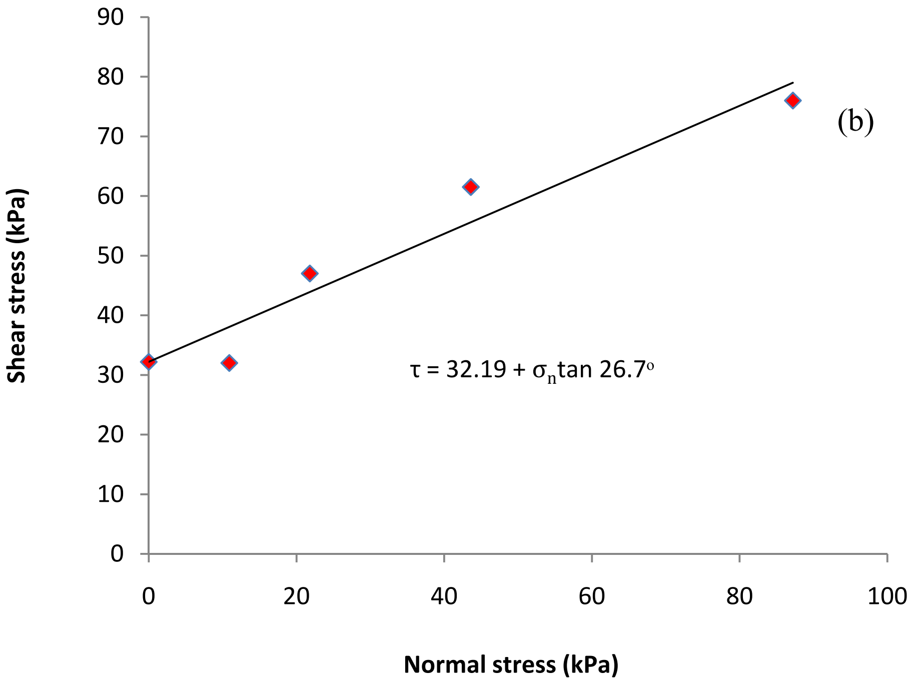


Figure (4): (a) Shear stress-strain (b) Strength envelope line of untreated soil

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California Bearing Ratio (CBR) Test

The soil specimen was compacted in three equal layers in a compaction mould with a diameter of 152 mm and a height of 178 mm at optimum moisture content and maximum dry density. In order to perform the CBR test, a plunger of a standard area was pushed into the compacted soil at a fixed rate of penetration and the force required to maintain that load was measured. The CBR value is then defined as the ratio of the measured force to that required for similar penetration into a standard sample of crushed California limestone rock (Goodary et al., 2012).

RESULTS AND DISCUSSION

Direct Shear

Untreated Soil

Direct shear test results of untreated soil specimen shown in Fig. 4 were developed by plotting shear stress-strain and shear stress-normal stress relationship with reference to four effective normal stresses of 10.90 kPa, 21.80 kPa, 43.60 kPa and 87.20 kPa. The test was carried out under drained loading conditions; i.e., no increase in pore pressure occurs. From Fig. 4 (a), it can be observed that shear stress was increased while horizontal strain increased until ultimate shear strength was reached. As shown on graphs, the curves of shear stress-strain are smooth level and flat out at the ultimate or critical values. This can be explained by the fact that in soft clays the peak stress is lower or even non-existent. Depending on normal stress, shear strengths of the soil varied greatly. The highest shear strength of the untreated soil specimen is corresponding to 87.20 kPa effective normal stress. In this case, the angle of internal friction and cohesion were determined and found to be 26.7^{o} and 32.19 kPa, respectively (Fig. 4 b). These results can be compared with the behavior of Ankara clay under direct shear test that was conducted by Cocka and Tilgen (2010). The shear stress-strain curves of Ankara clay at optimum moisture content are matched with direct shear curves of this paper. The internal friction angle and cohesion for Ankara clay were determined and found to be 31° and 94 kPa. The differences between the cohesions are due to different normal effective stresses and different nature of the soils.

Stabilized Soil

Shear stress of the compacted soil specimen at optimum moisture content and partial replacement of cement with 2% peat ash obtained through direct shear test is plotted *versus* horizontal strain in Fig. 5 (c) for the four normal effective stress ranges of 10.90 kPa, 21.80 kPa, 43.60 kPa and 87.20 kPa. Similar to untreated soil, shear stress of stabilized soil was increased while horizontal strain increased until ultimate strength was reached. From Fig. 5 (c), it can be seen that peak shear strength slightly appeared. This implies that the addition of 18% cement to soil specimen altered the test specimen to a hard state. In fact, 18% cement and 5% silica sand with 21.13% optimum moisture content produced strengthened material in the soil specimen. The strength envelope line was plotted by transporting the peak shear stresses to intercept ordinates along the normal stresses and the best fit straight line through the stress ratio points is the strength envelope line (Fig 5 d). Based on Fig. 5 (d), angle of internal friction and cohesion were determined and found to be 42.4^{o} and 92.7 kPa, respectively. Comparing the results of stabilized soil specimen with those of untreated soil reveals that the shear strength of stabilized soil was improved by almost 2.3-fold. This may happen due to the effects of the addition of cement and peat ash to the soil specimen. Furthermore, peat ash can fill the pore spaces of the soil due to its fineness; as such, it increases the inter-particle attraction of the clay. Therefore, the soil matrix will be reinforced and shear strength will improve.

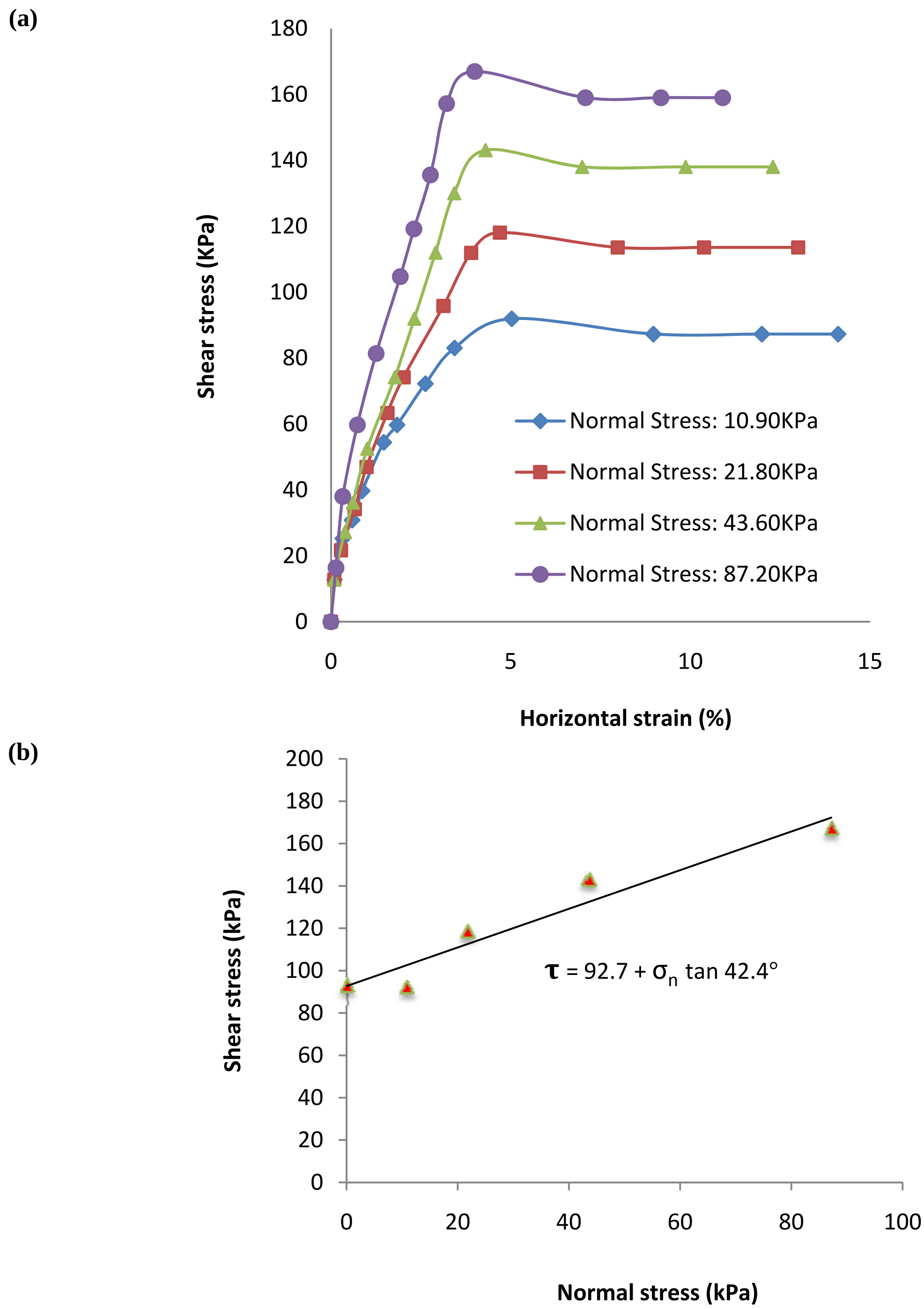

Figure (5): (a) Shear stress-strain (b) Strength envelope line of stabilized soil with OPC 18%, PA 2%, SS 5%

Unconfined Compression

Results of unconfined compression test of untreated and stabilized soil specimens for partial replacement of cement with 2% peat ash are indicated in Fig. 6. It can be seen that both unconfined compressive strength and axial strain were influenced by the cement replacement with peat ash. The values of unconfined compressive strength of untreated and stabilized soil specimens were determined and found to be 228 kPa and 396 kPa, respectively. This points out that the unconfined compressive strength of the stabilized soil specimen was improved by almost 1.7-fold. Furthermore, the addition of peat ash induced filler effect to soil specimen, binding soil particles. Based on Fig. 6 for stabilized soil specimen, vertical strain was determined and found to be about 5% which is 60% lower than that of the untreated soil specimen, The reduction of strain is due to the addition of 18% cement and 5% silica sand to the soil specimen. Since 18% cement acts as a hardening agent, 21.13% optimum water content of stabilized soil (Fig. 3) and compaction energy controlled the strain and resistance to deformation. Besides, the type of failure behavior of the test specimens varied greatly. The untreated soil specimen exhibited ductile behavior in failure under unconfined compression test; whereas, the stabilized soil specimen posed brittle behavior in failure. Such behavior in failure under unconfined compression test for 10% cement has also been reported by Horpibulsuk et al. (2010). Based on a study that was conducted by Bahar et al. (2004), unconfined compressive strength of compacted and stabilized clay with 10% cement was improved by almost 2.7-fold. This great improvement is due to the addition of cement to clay and dynamic compaction energy that yielded greater density of the stabilized soil.

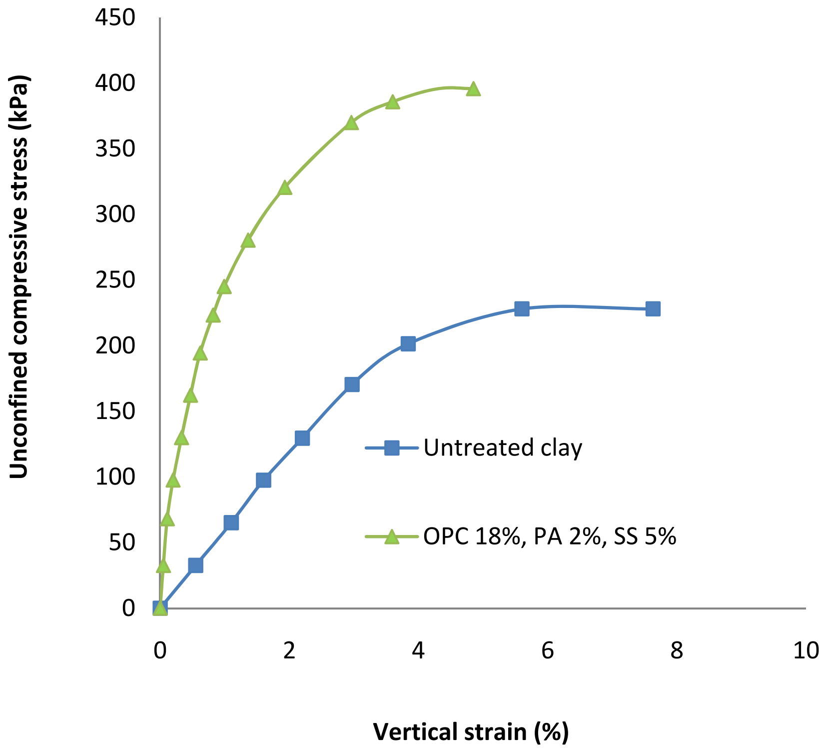

Figure (6): Effect of stabilization on unconfined compressive strength

California Bearing Ratio

Based on the results of the CBR test, graphical relationship of load-penetration was plotted (Fig. 7). The CBR values for untreated and stabilized soil specimens were determined and found to be 4.53 and 23.64, respectively. As indicated in Fig. 7, CBR of stabilized soil specimen is greater than that of untreated soil. Treating the soil with OPC as a cement additive, peat ash as a pozzolanic component and silica sand as a filler agent improved compact ability of the soil specimen. Vividly, the good compact ability is a significant factor of the soils that can induce high CBR and bearing capacity. The results of the CBR test can be supported by the findings of Goodary et al. (2012). According to Goodary et al. (2012), the CBR value of two different types of untreated soil were determined and found to be 9.5% and 14%. Likewise, the influence of stabilization with 9% cement and 20% coarse sand on CBR was investigated. The mean CBR values for stabilized soils were determined and found to be 83.8% and 122.7%. The difference between the results is due to the nature of the soils with different properties. The similar graphs of CBR test that match with the graphs of this paper were plotted by Goodary et al. (2012).

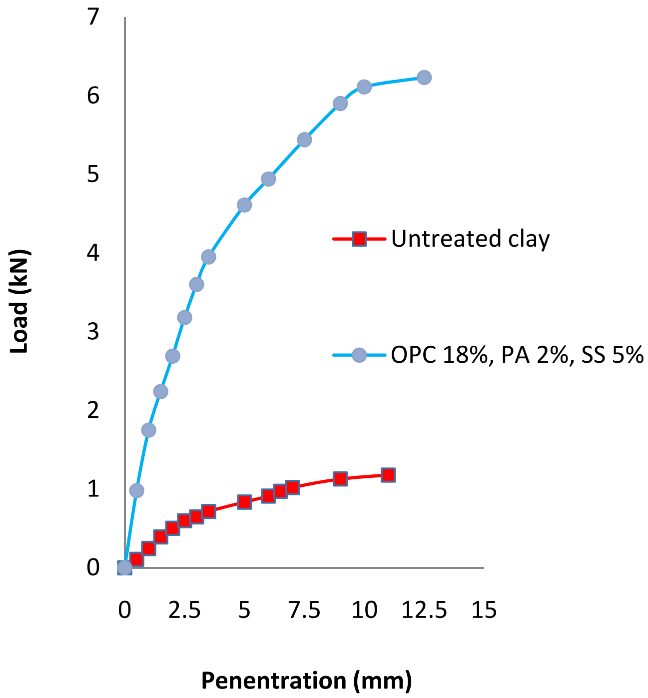

Figure (7): Load-penetration relationship

Scanning Electron Micrograph

Scanning electron micrograph (SEM) of stabilized soil specimen containing OPC 18%, PA 2%, SS 5% compacted at the optimum water content and maximum dry density under the standard Proctor energy is shown in Fig. 8. Based on microscopic evidence of the stabilized soil as shown in Fig.8, it is observed that the pore spaces were covered by the cement gel (hydrated cement) and the matrix of stabilized soil was improved. This implies that cement and peat ash had produced cementitious products due to pozzolanic reactivity. For this reason, the cementation contributed to the strong inter-particle bond that can offer greater shear strength of the stabilized soil (Wong et al., 2013). Similar improvement of the stabilized soil can be seen in the SEM photos of stabilized fine grained soil from the study of Horpibulsuk et al. (2010). SEM photos of the stabilized soils with 10% cement compacted at different water contents under the modified Proctor energy were analyzed by Horpibulsuk et al. (2010). Results have proven that the densest state of the stabilized specimen is at the optimum water content.

Figure (8): SEM of the stabilized clay

CONCLUSIONS

Influence of cement, peat ash and silica sand on shear strength, CBR and unconfined compressive strength of compacted clay was investigated in this paper. Oven dried clay was mixed with correct proportions of such additives and compacted to maximum dry density and optimum moisture content under standard Proctor test. The soil specimen related to partial replacement of cement with 2% peat ash was chosen to perform direct shear, unconfined compression and CBR tests. The following conclusions are drawn from the results of this paper.

1. Based on the results of direct shear and unconfined compression tests, ordinary Portland cement can be partially replaced with peat ash.
2. Based on filler effect of the peat ash, pore spaces of the stabilized soil were covered and the matrix of the soil improved as indicated in SEM of the stabilized clay.
3. The addition of cement to soil specimen decreased the ductility behavior of the soil specimen in failure and altered it to brittle as evident in its steep linear elastic unconfined compressive stress-vertical strain curve.
4. It was found that the shear strength of the stabilized soil specimen containing 2% peat ash is 2.3-fold greater than that of untreated soil under the application of 87.20 kPa effective normal stress.
5. The unconfined compressive strength of stabilized clay is 1.7-fold greater than that of the untreated soil specimen.
6. As for the CBR value, it was found that the CBR value of stabilized clay increased drastically in comparison with the CBR of untreated soil specimen.

The results of laboratory investigation revealed that cement can be partially replaced with peat ash, and peat ash can be optimized in the stabilized clay to improve the soft clay for the construction purpose, especially highway construction on soft clayey grounds.

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