

Utilization of Brown Clay and Cement for Stabilization of Clay

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ABSTRACT

This paper investigates the utilization of brown clay and cement in order to stabilize soft clay. Brown clay mixed with a suitable amount of cement paste is capable to impart filler and pozzolanic effect. Therefore, the mechanical behavior of the soil would be improved. Treatment of fine grained soils with cement is not novel. While stabilization of fine grained soil with brown clay has not been completely investigated, this paper attempts to assess the mechanical behavior of treated soil with cement and brown clay. Laboratory investigations include direct shear, vane shear, unconfined compression and CBR tests which were applied on the test specimens. In addition, laboratory compaction test was performed to supply the soil specimens with optimum moisture content and maximum dry density. The outcome of the study is an optimal mix design of stabilized clay, which can be applied to improve soft clay. For the optimal mix design, binder composition of cement 8.5%, brown clay 1.5%, silica sand 5% was obtained. Therefore, input cement can be saved due to partial replacement of ordinary Portland cement with 1.5% brown clay.

KEYWORDS: Stabilized clay, Silica sand, Brown clay, Highway construction, Vane shear.

INTRODUCTION

Stabilization of fine grained soils with cement is not new. This technique is widely used to improve the properties of problematic soils. So far, suitable researches have not been carried out to stabilize clayey soils with cement and brown clay. The primary motivation of this study was to investigate the innovative use of brown clay and cement to improve mechanical behavior of the soil specimen. Previous researches have proven the possibility of the use of kaolin and sodium bentonite as partial cement replacement materials in the stabilization of soils. Research works on stabilized fine grained soils with cement, natural pozzolans, fly ash, lime and hay fibers have been carried out by Horpibulusk et al. (2010), Horpibulusk et al. (2011), Horpibulusk et al. (2012),

Wong et al. (2013), Hossain and Mol (2011), Yilmaz et al. (2013), Mohamed (2013), Bahar et al. (2004), Goodary et al. (2012), Maio et al. (2004) and Sariosseiri and Muhunthan (2009). According to Mohamed (2013), addition of 1.5% hay fibers reduced the free swelling of the soil specimen by almost 20%. Based on Bahar et al. (2004), treated soil specimen with 10% cement indicated the highest unconfined compressive strength and the lowest permeability as well as shrinkage. Goodary et al. (2012) have investigated strength development in cement stabilized soil on two types of volcanic soils. Based on the findings by Goodary et al. (2012), treated samples of both soil specimens with 9% cement and 20% coarse sand exhibited the highest value of CBR. Wong et al. (2013) reported that kaolin and sodium bentonite when blend with organic peat can exhibit the pozzolanic and filler effect to increase the strength of soil due to their fineness. According to Maio et al. (2004) stabilization

of fine grained soil with cement increases the base material's strength and reduces deflection and ductility form. The most critical problem and major concern of highway construction over soft and low shear strength clay is excessive total and differential settlements. To improve bearing capacity, compaction characteristics and shear strength of the soil specimen, various proportions of cement and brown clay were mechanically mixed with clay and test specimens provided. Other than cement and brown clay, silica sand was used to modify the grain size distribution of the soil specimen. The test specimens were tested at optimum moisture content and maximum dry density. Besides, the pore spaces of the soil specimen were filled up and its matrix improved due to filler effect of brown clay on cemented soil. Thus, the stabilized soil with sufficient bearing and strength can be applied in field applications such as highway construction. Since, stabilized soil with appropriate thickness will be placed under the highway construction to protect it and limit the settlement. According to Taleb et al. (1995), cement industry generates dust during its production and cement dust causes damage to health and environment. Therefore, it is important to utilize brown clay to minimize the amount of cement and save the amount of input cement. The specific objective of this paper was to evaluate the mechanical behavior of treated soil with cement and brown clay. Thus, an optimal mix design was extracted from the results of this study.

MATERIALS AND METHODS

Soil Sample Collection

For the purpose of stabilization, the soil sample was obtained from Taman Wetlands, Putrajaya, Selangor, Malaysia (Fig. 1).

In order to collect the soil sample, block sampling method was used. For the purpose of this study, a tin-walled polyethylene tube with a diameter of 100 mm was used. About 30 cm thick layer of the top soil comprising leaves and roots was clearly removed from

the area. The soil was excavated until the water table was observed at a depth of 1.5 m below the ground surface. The tube was pushed into the soil under water table and was then immediately kept in laboratory facilities and transported to laboratory. Soft clay ranged at about 2 meter depth from the ground surface, underlain by a layer of hard clay. In the initial observation and investigation, the soil was found to be light brown in color with some leaves and roots. The soil sample was classified as CLAY of high plasticity (CH) according to the Unified Soil Classification System (USCS) and composed of 23% sand, 15% silt and 62% clay. A natural pozzolan in form of brown clay was obtained for the research at a site near Infrastructure University Kuala Lumpur (IUKL). In the initial observation of the eight excavated trail pits, the ground water surface was observed at about 1 meter below the ground surface. The brown clay ranged at about 2 meter depth from the ground surface, underlain by a coarse grained soil. Initial investigation on brown clay in laboratory revealed that soil was of high plasticity, high compressibility and high moisture content.

The particle size distribution curves of soft clay and brown clay are shown in Fig. 3.

Table 1 illustrates the index properties of the soil sample.

Laboratory Mix Design

In order to stabilize the soil, various percentages of Brown Clay (BC) and Ordinary Portland Cement (OPC) were mechanically mixed with soil and compacted in three equal layers to obtain the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). Other than cement and brown clay, Silica Sand (SS) was used to modify the grain size distribution of the soil specimen. Table 2 summarizes the mix design of stabilized soil in terms of MDD and OMC.

Test Set-up

To evaluate compactability and strength of both

untreated and stabilized soil specimens, laboratory compaction, direct shear, unconfined compression and California Bearing Ratio (CBR) tests were performed. The test methods described in this paper are based on

the standard ASTM and BS guidelines. In addition, organic content and pH tests were carried out in accordance with BS 1377: 1990.



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



Figure (2): Oven dried brown clay

Standard Proctor Compaction Test

The collected soil sample was exposed to air at room temperature until it thoroughly dried. Based on Table 2, certain proportions of cement, brown clay and silica sand were mixed with the soil. The soil specimen was compacted by drop weight method by 25 blows in three equal layers in a compaction mould with a diameter of 101.50 mm and a height of 107 mm. Maximum dry density and optimum moisture content

for each test specimen were calculated. The test method was based on ASTM D 698.

Direct Shear Test

The compacted soil specimen with optimum moisture content and maximum dry density was taken out from the compaction mold; and the square soil specimen with a dimension of 60 mm and a height of 30 mm was cut from the circular soil specimen. Porous

platens were positioned at the bottom and top of the specimen. The rate of shearing was adjusted at 0.5 mm/min. The test specimen was sheared in a 60 mm

square shear box under 87.20 kPa normal stress. The test method was based on ASTM D 3080.

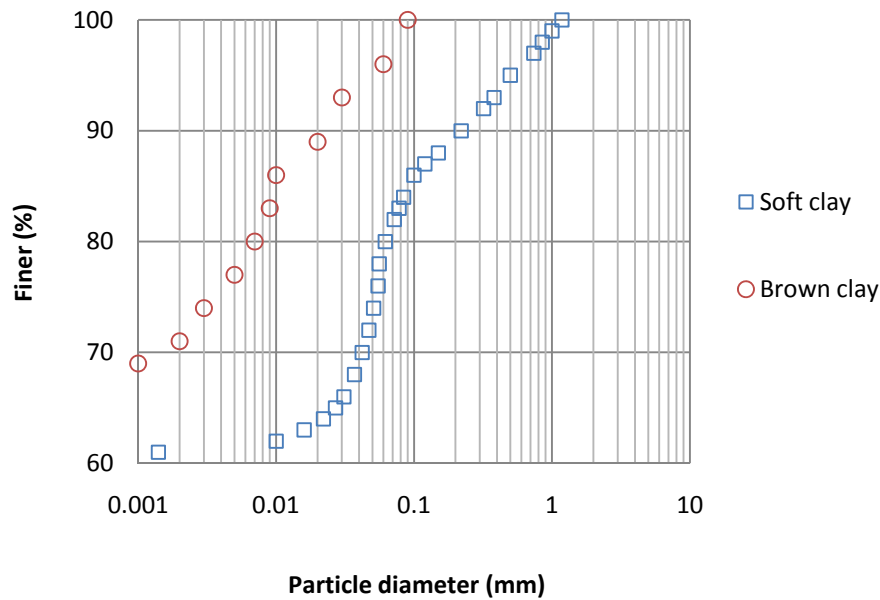


Figure (3): Particle size distribution curves of soft clay and brown clay

Table 1. Index properties of the soft clay

Property	Index value
Natural moisture content	45%
Specific gravity	2.46
Liquid limit	55.76%
Plastic limit	24.44%
Plasticity index	31.32%
pH	7.1
Organic matter	5.3%
Fiber content	21.15%
Maximum dry density	1.782 Mg/m ³
Optimum moisture content	16.32%
Coefficient of permeability at 20°C	11.44×10 ⁻⁸ ms ⁻¹

Unconfined Compression Test

For the purpose of unconfined compression test, a compaction mould was used to prepare cylindrical compacted test specimens. The compaction mold was of a height-to-diameter ratio of 1.82. Before

compaction, the inner surface of the mould was lightly lubricated. The provided soil specimen at optimum moisture content was placed into the mould and compacted in three equal layers through tamping with a tamper consisting of a circular disk attached to a steel

rod. The disk had a diameter slightly less than the mould. The two longitudinal split parts of the mould were removed from one another, and the cylindrical specimen was gently released. The bottom and top of the specimen were trimmed to obtain the required

height of specimen. All the specimens were prepared as 50 mm in diameter and 91 mm in height. Unconfined compression test was performed as soon as the test specimen was supplied. The test method was based on ASTM D 2166.

Table 2. Effect of binder dosage on compaction characteristics of the stabilized soil

Binder composition by dry weight of the soil (%)			MDD (Mgm ⁻³)	OMC (%)
(OPC)	(BC)	(SS)		
10	0	5	1.864	17.81
9.50	0.50	5	1.870	17.73
9	1	5	1.878	17.12
8.50	1.50	5	1.903	16.51
8	2	5	1.882	16.02

Vane Shear Test

The vane shear apparatus is a hand-held device that is made for laboratory testing purposes. Based on BS 1377: 1975 for performing the vane shear test, the compaction mould containing soil specimen at optimum moisture content was placed in the vane shear apparatus vertically below the vane shaft. The test started and the vane was pushed into the soil specimen, and torque was set up in the spring resisted by the soil specimen. Then torque was increased until the soil specimen sheared. Meanwhile, spring deflection at failure and deflection of the vane were recorded simultaneously. The experimental data obtained from laboratory vane shear test were analyzed to establish a relationship between vane shear strength and maximum dry density of the soil specimen. The vane shear strength of the soil specimen is formulated in equation 1 (Das, 1989).

$$S_u = k(\theta_f)/4.29 \text{ kN/m}^2 \quad (1)$$

where

S_u = vane shear strength in kN/m² (undrained shear strength).

k = torsional constant of the spring in Newton meter per degree.

θ_f = spring deflection in degrees (inner scale).

California Bearing Ratio (CBR) Test

The soil specimen at optimum moisture content was compacted in three equal layers in a mould with a diameter of 152 mm and a height of 178 mm. 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 (ASTM D 698).

RESULTS AND DISCUSSION

Standard Proctor Compaction

To determine compaction properties of the stabilized soil, various percentages of brown clay (Table 2) by the weight of soil were mechanically mixed with the soil specimen and a rather homogeneous mixture was generated. Other than brown clay and ordinary Portland cement, silica sand was used to modify grain size distribution of the soil specimen. The provided soil specimen was placed in a compaction mould and compacted in three equal layers to obtain optimum water content and maximum dry density. Results of treated soil with various dosages of cement and brown clay are illustrated in Figure 4. From Figure 4, it can be observed that the highest value

of MDD is corresponding to binder composition of OPC 8.5%, BC 1.5%, SS 5%. This may be due to the filler effect of the brown clay on cemented soil that decreases the pore spaces. On the other hand, addition of silica sand to the soil specimen modified grain size distribution and increased the compactability of the soil specimen. Comparison of the moisture content of the binder composition of OPC 10%, BC 0%, SS 5% with specimens stabilized with cement and 0.5%, 1%, 1.5%, 2% brown clay indicates that the stabilized soil

specimens with brown clay were consistently attained on the dry side of the optimum moisture content from the compaction Proctor test. A similar investigation was conducted by Horpibulsuk et al. (2011) on stabilized soil. Bangkok clay was stabilized with cement and fly ash. Horpibulsuk et al. (2011) have found the maximum value of MDD for binder composition of Bangkok clay with 20% Portland cement and 25% fly ash. The difference between the results is due to the different binder types and dosages.

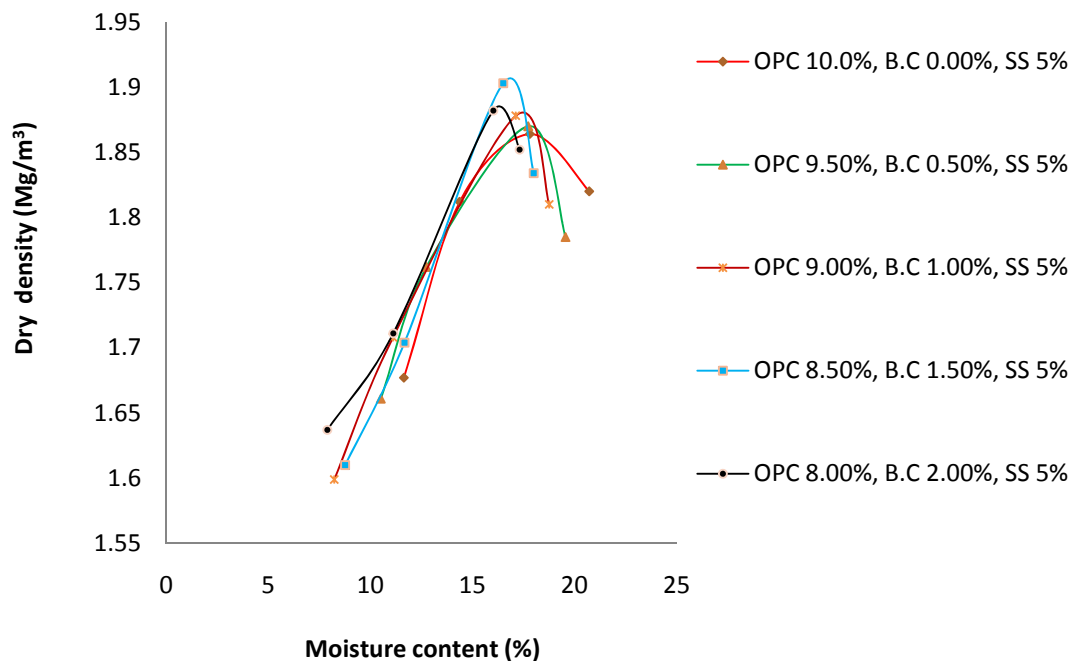


Figure (4): Effect of brown clay on dry density and moisture content of stabilized clay

Direct Shear

The compacted soil specimen at optimum moisture content with various percentages of cement and brown clay was placed in a square shear box. The soil specimen was sheared under 87.20 kPa normal stress and the results were analyzed to obtain the required shear strength parameters. The typical shear stress – horizontal strain curves for both untreated and stabilized test specimens are plotted in Figure 5. As shown in Figure 5, the shear stress increased while the horizontal strain increased until the ultimate shear

stress was reached. For the soil specimens, the peak shear strength was not observed, thus soil was stated in normal consolidation condition. Results show that maximum shear strength was obtained for binder composition of OPC 8.5%, BC 1.5%, SS 5%. Based on particle size analysis, the average particle diameter of brown clay is finer than that of soft clay. Thus, the fineness of brown clay enables soft clay to bring filler and pozzolanic effect to cemented soil. Therefore, the smaller particles of brown clay were decreasing the pore spaces of the cemented soil, thus the soil texture

was improved and yielded the maximum shear strength. Meanwhile, higher percentage of brown clay; i.e., more than 1.5%, led to reduction in the shear strength of the soil specimen. This result can be supported with the results of a study conducted by Mohamed (2013). Similar behavior and pattern were

observed by Mohamed (2013) for stabilization of clay with 0.5%, 1%, and 1.5% hay fibers. Mohamed (2013) also has found that addition of 0.5% and 1% hay fiber is effective while the influence of 1.5% hay fiber is little.

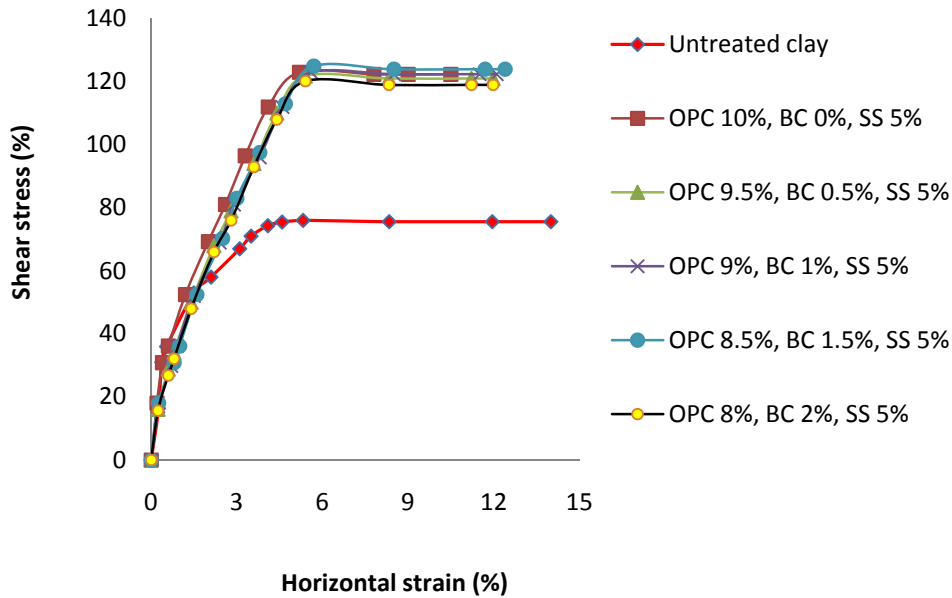


Figure (5): Shear stress-strain relationship of cemented clay

Unconfined Compression

The unconfined compressive stress-strain relationship for both untreated and stabilized soil specimens at optimum moisture content is shown in Figure 6. From Figure 6, it can be seen that addition of brown clay to stabilized soil specimen has increased the unconfined compressive strength. The significant influence for stabilized soil was obtained with 1.5% brown clay. This phenomenon occurs because adequate brown clay imparted a commensurate filler effect to soil specimen; thus, the matrix of the soil improved and unconfined compressive strength increased. The positive result implies that ordinary Portland cement can be partially replaced with 1.5% brown clay. These results can be compared with the results of stabilized clay with 10% cement by Bahar et al. (2004). The difference between the results is due to different soils,

binder types and binder dosages.

Vane Shear

The relationship between vane shear strength and maximum dry density of the soil specimens is illustrated in Figure 7. The compacted soil with various proportions of cement and brown clay at optimum moisture content was tested under laboratory vane shear test. From Figure 7, it can be observed that addition of 0.5% to 2% brown clay has increased the vane shear strength of the stabilized soil specimens compared to that of untreated soil. Based on Figure 7, all binder dosages have increased the vane shear strength and the significant influence on the vane shear strength is corresponding to binder composition of OPC 8%, BC 2%, SS 5%. Herein, fine particles of brown clay fill up the pore spaces of the cemented soil

and cement binds the particles and increases inter-particle attraction of the soil; thus, the matrix of soil

specimen was reinforced and improved.

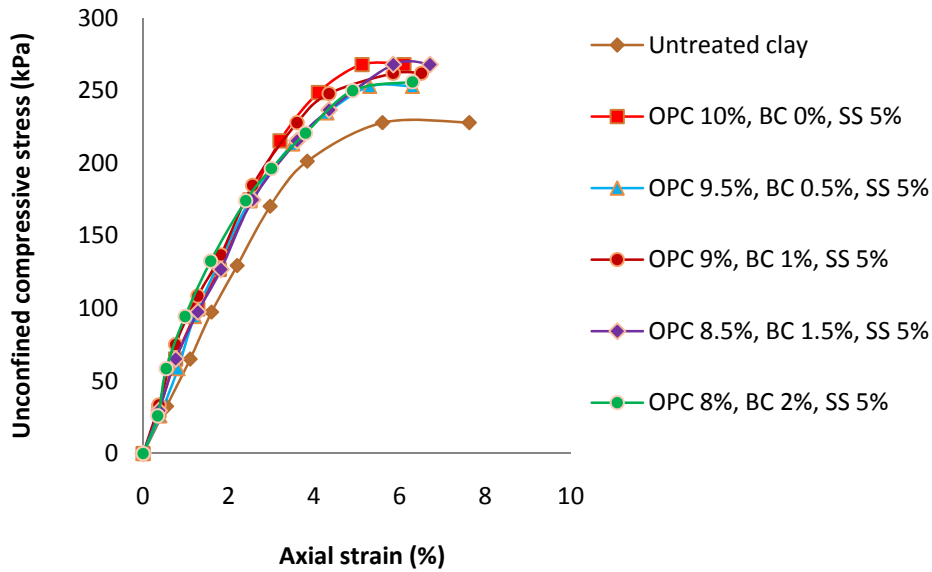


Figure (6): Unconfined compressive strength of stabilized clay

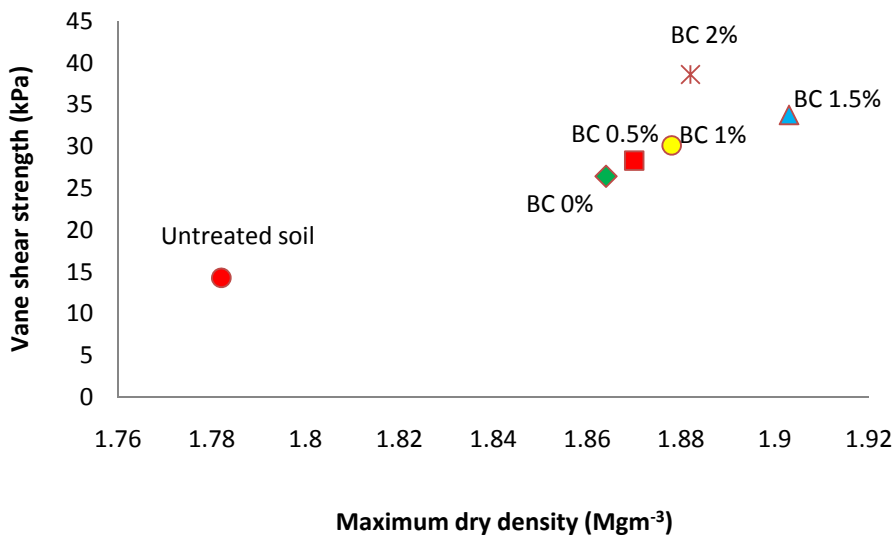


Figure (7): Effect of maximum dry density on vane shear strength of the soil specimens

CBR

The effect of stabilization of soft clay at optimum moisture content and maximum dry density with cement and brown clay on CBR value is indicated in Figure 8. Based on Figure 8, addition of cement and

brown clay to soil specimen improved CBR of the soil specimens. However, the effect of stabilization in CBR is not great. As shown in the graphs, binder composition of OPC 8.5%, BC 1.5%, SS 5% yielded the highest CBR. Besides, influence of brown clay

dosage on CBR is indicated in Figure 9. As shown in the graph, 1.5% brown clay in stabilized soil yielded the maximum CBR. Results of the CBR test can be compared with the findings of Goodary et al. (2012). According to Goodary et al. (2012), the CBR values 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 reported. 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 types of soil, their properties and different stabilizers in cemented soil.

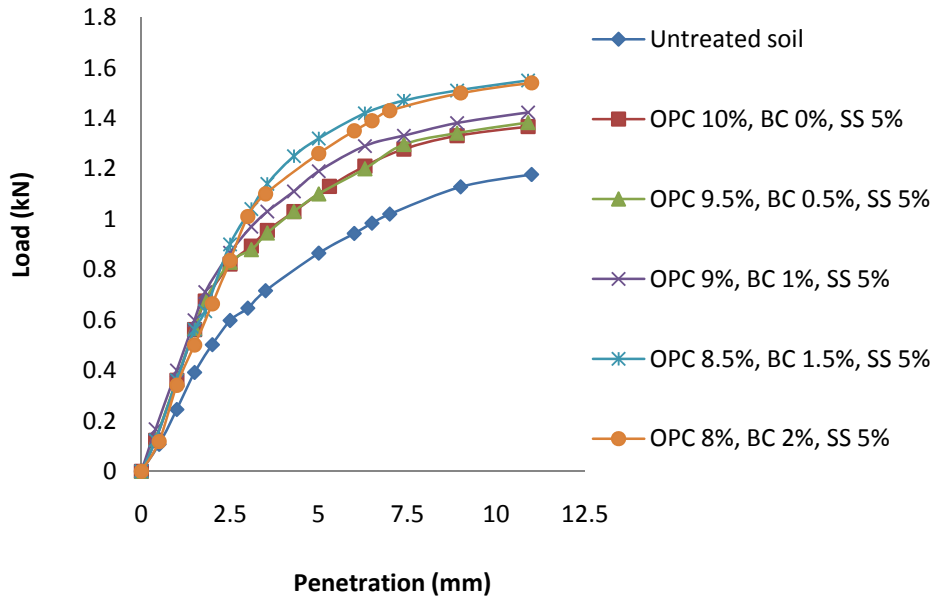


Figure (8): Load-penetration relationship of the soil specimens

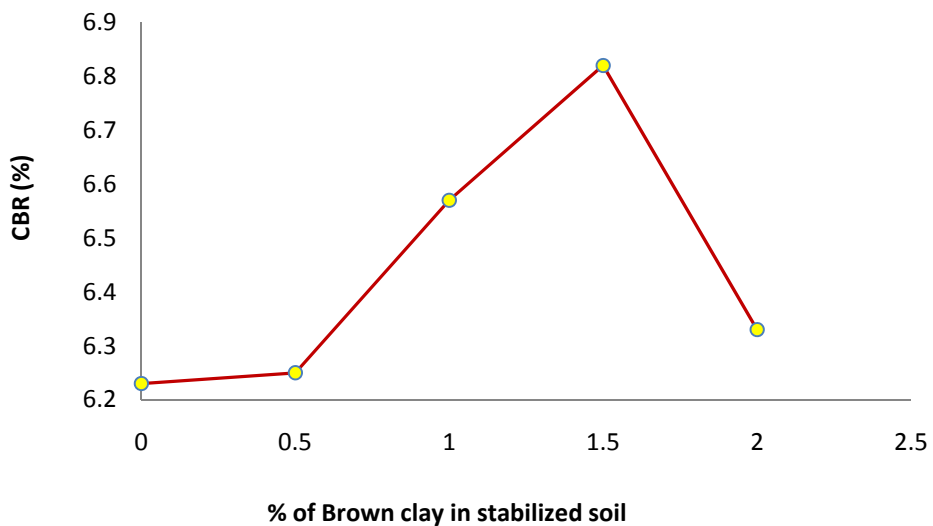


Figure (9): Effect of brown clay dosage on cemented soil specimen

CONCLUSIONS

In this paper, various percentages of Ordinary Portland Cement (OPC) and Brown Clay (BC) were mixed with the soil specimen and compacted at optimum moisture content. The compacted soil specimen with maximum dry density and optimum moisture content was tested under direct shear, unconfined compression, vane shear and CBR tests. The following conclusions are drawn from this paper.

(1) Results of analysis reveal that brown clay mixed with cemented soil influences the shear and

unconfined compressive strength of the soil specimen.

(2) The optimal mix design of stabilized soil was determined for binder composition of OPC 8.5%, BC 1.5%, SS 5%. Besides, ordinary Portland cement was partially replaced with 1.5% brown clay. Therefore, the input cement can be saved due to partial replacement of ordinary Portland cement with brown clay.

(3) The percentages of improvement in strength and maximum dry density of stabilized soil proven with laboratory investigation are shown in Table 3.

Table 3. Percentage of improvement of stabilized soil with brown clay

Mechanical behavior	Untreated soil	Stabilized soil (OPC 8.5%, BC 1.5%, SS 5%)	Percentage of improvement
Maximum dry density (Mg/m ³)	1.782	1.903	6.8
Shear strength (kPa)	76	125	64
Unconfined compressive strength (kPa)	228	268	17
CBR (%)	4.53	6.82	50
Vane shear strength, S _u (kPa)	14.3	33.8	2.36-fold

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