Mechanical Behavior of Compacted and Stabilized Clay with Kaolin and Cement

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ABSTRACT

This paper focuses on the potential use of kaolin and cement for stabilization of soft clay and the application of stabilized soil as a highway embankment material. The problem of soft clay which is encountered in many geotechnical projects is its low shear strength and bearing capacity due to poor engineering properties of the soil. Therefore, soft clay has to be improved before any ground improvement work can commence. The mechanical behavior of stabilized soil was investigated on the basis of standard Proctor compaction, California bearing ratio (CBR), unconfined compression and direct shear tests. The main objective of this paper is to assess the mechanical behavior of treated soil with cement and kaolin. The results of laboratory investigation indicate an increase in the shear strength, CBR value and unconfined compressive strength of the treated soil with binder composition of OPC 8%, K 2% and SS 5%. Besides, it was proven that engineering characteristics of stabilized soil with binder composition of OPC 8%, K 2% and SS 5% are superior to those stabilized with lower percentages (i.e., less than 2%) of kaolin. The outcome of the study is an optimal mix design of stabilized clay, which can be applied to improve soft clay. It is revealed that ordinary Portland cement can be partially replaced with 2% kaolin. Furthermore, the stabilized soil with cement and kaolin can be applied in highway construction; however, sufficient laboratory and *in situ* testing is needed before proceeding to field trial.

KEYWORDS: Kaolin, Silica sand, Ordinary Portland cement, Stabilized soil.

INTRODUCTION

Soil sustainability has often been the main concern of researchers in geotechnical sciences, and civil engineers have always looked for solutions to stabilize and sustain the soil besides having an economical design (Laufer, 1967). Thus, different ways such as mechanically stabilized earth, micro pile, sand drain, anchorage, nailing and using admixtures have been evaluated and employed so far. These methods, in addition to achieving good results would impose high costs on the shoulders of the company or individual. Construction works, such as dams, road embankment and highway construction that would locate on soft clay need stabilization and improvement technique to achieve the desired engineering characteristics of base soil. The stabilized soil with sufficient thickness and proper properties can be placed under such constructions 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

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capacity will be improved (Hossain and Mol, 2011). One of the methods currently used in most cases is grouting, in which by injecting cement or a suitable material into the soil structure and thorough boreholes made in the project location, it is tried to reform the fractures and cracks that reduce soil strength (Baghdadi, 1990). This paper attempts to stabilize and improve the mechanical behavior of soft clay by adding various proportions of cement, kaolin and silica sand. Stabilization of clay with cement has been extensively researched by Cocka and Tilgen (2010), Yin and Lai (1998), Terashi et al. (1979), Kasama et al. (2000), Kawasaki et al. (1981), Consoli et al. (2000), Clough et al. (1981), Uddin (1994) and Kamon and Bergado (1992). Previous research works have proven that addition of cement to soil specimen can change the failure behavior of soil to brittle (Yilmaz and Ozaydin, 2013). Based on the research work conducted by Nazir and Azzam (2010), soft clay which exhibits poor strength, such as clay deposited in coastal areas, can be improved with cement and sand. This paper aims to use a mineral material called kaolin, previously named Porcelain soil, in order to stabilize the soil of the examined region. Kaolin is a commercial term which is used for almost-white clay deposits. These deposits mostly conclude kaolinite deposits or products made of it. The term kaolin is derived from Chinese Kao-Ling, meaning white hill from which kaolin soil was extracted. White kaolin or Porcelain soil is mostly employed in producing Porcelain and ceramic. United States, Russia, Czech Republic and Brazil are among the greatest producers of kaolin (Eisazadeh et al., 2011). The objective of this paper is the assessment of mechanical behavior of stabilized soil with cement, kaolin and silica sand. The expected outcome of this paper is an optimal mix design of compacted clay stabilized with cement, kaolin and silica sand that can be efficiently utilized to improve grounds with shallow clay for highway construction.

Sample Collection and Material Characteristics

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. In initial investigations and observations, the soil was found light brown in color with some leaves and roots on the surface. Based on Unified Soil Classification System (USCS), the soil was classified as silty sandy CLAY. The type of cement for this study is Ordinary Portland Cement (OPC) from the YTL Company. White kaolin was prepared from the Kaolin Malaysia Limited. Silica sand was collected nearby CE-Laboratory of UNITEN, Malaysia. The particle size distribution curves of soft clay, kaolin and silica sand are illustrated in Figure 1. In addition to grain size distribution curves, the basic properties of soft clay, kaolin and silica sand are tabulated in Table 1.

Test Setup and Methods

As shown in Table 2, the influence of kaolin on cemented soil was examined by decreasing cement content from 10% to 8% and simultaneously increasing kaolin from 0% to 2% in stabilized test specimens. Aside from cement and kaolin, 5% of silica sand was added to the test specimen in order to modify the grain size distribution of the soil. Then, the above mentioned materials were mixed with water and compacted in three equal layers in order to have homogeneous specimens. The optimum moisture content and maximum dry density were obtained from the compacted soil through the standard Proctor compaction test. The stabilized soil specimen which had the highest maximum dry density was chosen for further laboratory tests. The laboratory tests are based on standard US-ASTM and BS guidelines.

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 prepare the stabilized test specimen, binder composition of OPC 8%, K 2% and SS 5% was mechanically mixed with an oven dried soil specimen.

(OPC=ordinary Portland cement; K=kaolin; SS=silica sand; OMC=optimum moisture content; MDD= maximum dry density). Then, 17.07% optimum water content (Table 2) was added to the mixture and thoroughly mixed until a homogeneous mixture was obtained. The provided soil was placed in a compaction mould and was compacted in three equal layers. Then, the specimen was taken out from 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 an assembled shear box was placed in a direct shear apparatus with an applied shear rate of 0.5 mm/min.

Table 1. Characteristics of materials

Properties	**Index value**		
	Soft clay	**Kaolin**	**Silica sand**
Natural moisture content	45%	dry	dry
Specific gravity	2.46	2.61	2.71
Liquid limit	55.76%	44.12%	Non
Plastic limit	24.44%	22.41%	Non
Plasticity index	31.32%	21.71%	Non
pH	7.1	7.3	10.3
Organic matter	5.3%	Non	Non
Fiber content	21.15%	Non	2.3%
Maximum dry density	1.782 Mg/m^3	1.63 Mg/m^3	1.58 Mg/m^3
Optimum moisture content	16.32%	18.1%	16.4%
Coefficient of permeability at 20°C	11.44×10^{-8} ms^{-1}	5.80×10^{-10} ms^{-1}	1.31×10^{-5} ms^{-1}

Table 2. Effect of mix design on compaction properties

Description	**Clay (%)**	**OPC (%)**	**K (%)**	**SS (%)**	**MDD (Mg/m^3)**	**OMC (%)**
Untreated soil	100	-	-	-	1.782	16.32
Stabilized soil with kaolin and cement	85	10	0	5	1.864	17.81
	85	9.75	0.25	5	1.870	17.78
	85	9.50	0.50	5	1.874	17.70
	85	9.25	0.75	5	1.879	17.61
	85	9	1	5	1.887	17.50
	85	8.75	1.25	5	1.891	17.38
	85	8.50	1.50	5	1.895	17.30
	85	8.25	1.75	5	1.899	17.23
	85	8	2	5	1.911	17.07

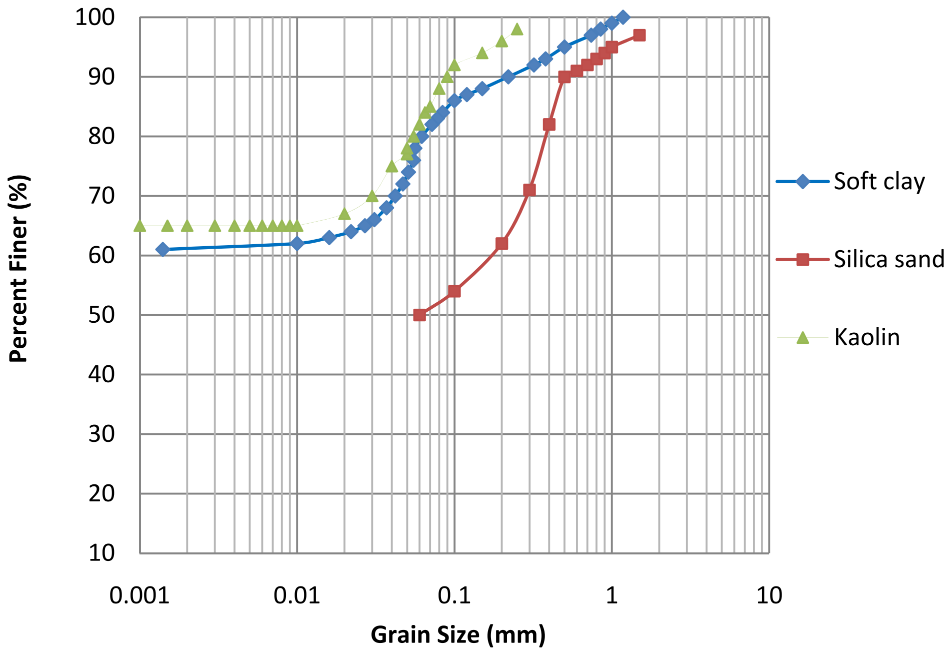

Figure (1): Particle size distribution curves

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. A blend of cement, kaolin, silica sand and soft clay was prepared as the binder composition. The employed materials included OPC 8%, K 2% and SS 5% (by weight), which is in accordance with the result of standard Proctor compaction test. A compaction mould with a diameter of 50 mm and a height of 91 mm was used to prepare both untreated and stabilized soil specimens. The cylindrical mould apparatus was made of stainless steel and split into two parts longitudinally. Before compaction, the inner surface of the split mould was lightly lubricated to prevent the specimen from being damaged while being removed from the compaction mould. Next, the mould was assembled and the soil specimen was poured into the mould in three equal layers. Each layer was compacted to a height of 30.3 mm using a stainless steel tamp with a base diameter of 49 mm to achieve the desired maximum dry density before placing the next layer. After placing the last layer, the top and bottom end rings of the compaction mould were unfastened. Finally, the two longitudinal split parts were removed from one another, and the cylindrical specimen was gently released. 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 the apparatus. The test was performed immediately after the specimen was removed from the cylindrical mould as drying will alter its characteristics considerably.

CBR Test

The untreated and stabilized soil specimens were 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 for maintaining that load was measured. The CBR value is then defined as the ratio of the measured force that is required for a similar penetration into a standard sample of crushed California limestone rock.

RESULTS AND DISCUSSION

Standard Proctor Compaction

Results of the MDD and OMC tests for stabilized soil with cement and kaolin are shown in Figure 2. Based on Figure 2, the binder composition of OPC 8%, K 2% and SS 5% has the highest value of MDD. This may be due to the fineness of kaolin that enables the clay to bring filler effect on cemented soil, so the pore spaces of the clay were filled, the structure of soil was influenced and properties of the soil specimen were improved. In fact, kaolin slipped the soil particles over together and bound the particles; thus it modified the treated soil specimen into a packed and dense state. Besides, the result of standard Proctor compaction test implies that OPC was partially replaced with 2% kaolin. Such discussion on stabilized soil with kaolin can be seen in the study conducted by Wong et al. (2013).

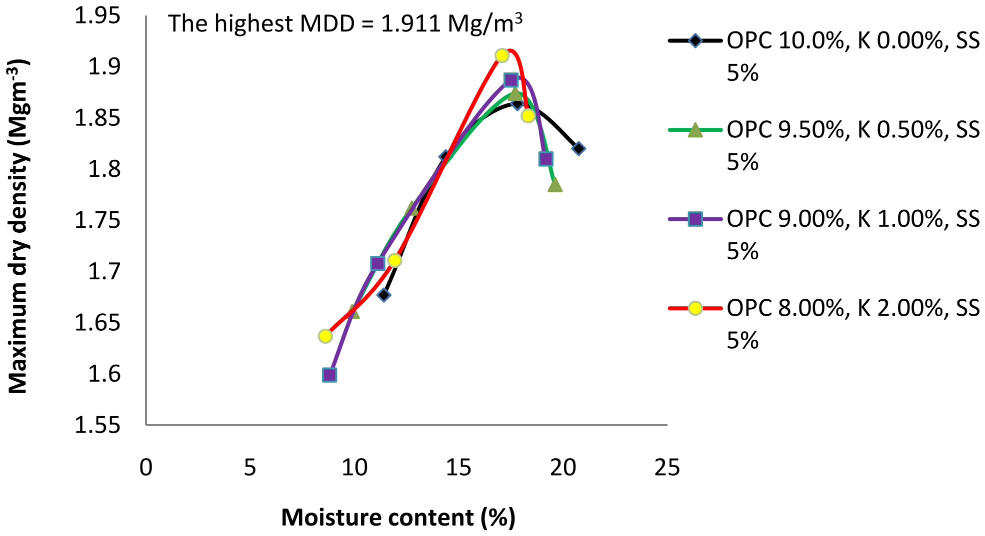

Figure (2): Effect of kaolin on dry density and moisture content of clay

Direct Shear

Untreated Soil

Figures 3 and 4 indicate the graphical relationships of shear stress-normal stress and vertical displacement-horizontal displacement of untreated clay obtained from laboratory direct shear test, respectively. Based on Figure 3, shear stress of the soil specimen increased by increasing the level of normal stress from 10.90 kPa to 87.20 kPa. This implies that the soil specimen was consolidated under great normal loads and exhibited higher shear strength. The test was carried out under drained loading conditions; i.e., no increase in pore pressure occurred. The maximum value of drained shear stress is determined to be 76.05 kPa under application of effective normal stress of 87.20 kPa. The strength envelope line obtained from laboratory direct shear test is plotted in Figure 3. As shown in Figure 3, the values of internal friction angle and cohesion of untreated clay were determined to be 26.7° and 32.19 kPa, respectively. The vertical-horizontal displacement relationship of untreated and stabilized soil is illustrated in Figure 4. As it can be seen, horizontal displacement increased while vertical displacement was increasing. This happens due to change of volume in soft clay. In soft clay, during shearing process under shear box, the volume of soil will decrease until the ultimate or critical strength is reached.

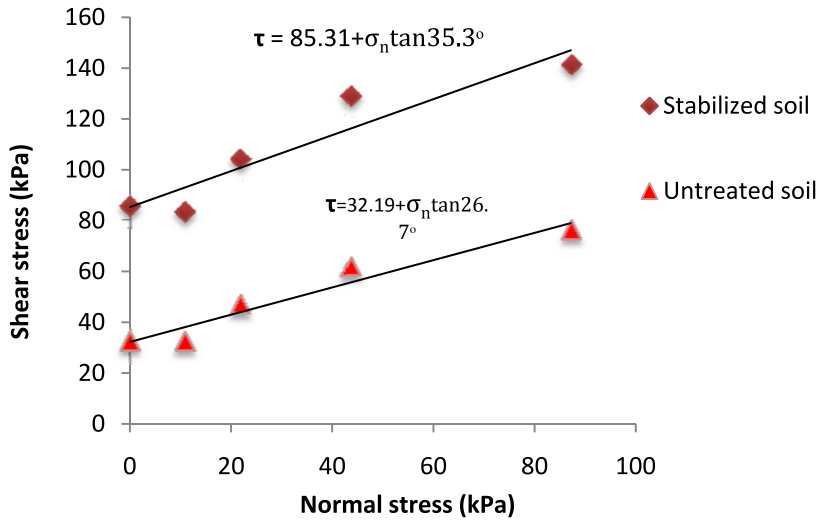

Figure (3): Shear stress-normal stress relationship of untreated and stabilized soil

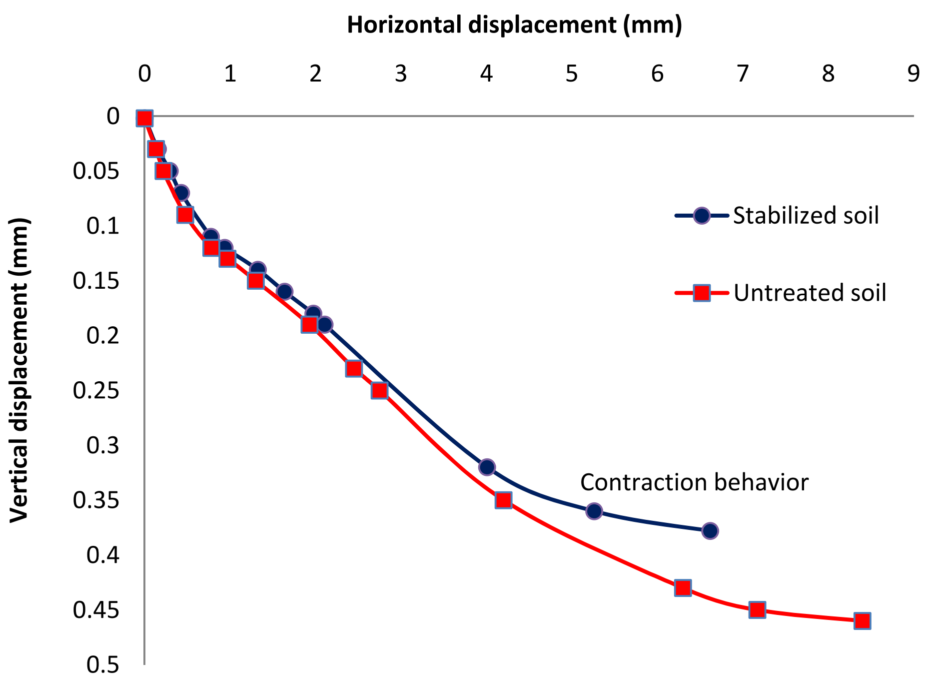

Figure (4): Vertical disp.-horizontal disp. relationship of untreated and stabilized soil under application of 32 kg normal load

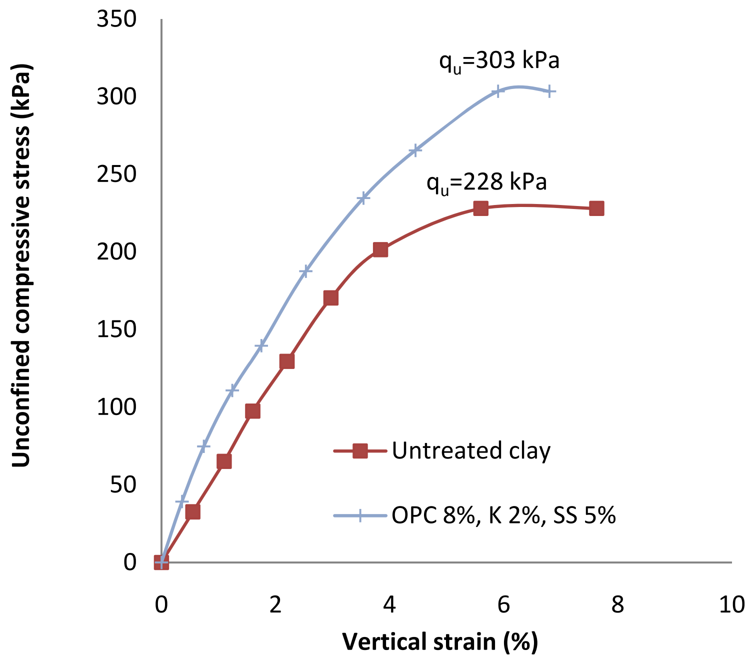

Figure (5): Unconfined compressive stress-vertical strain relationship for untreated and stabilized soil specimens

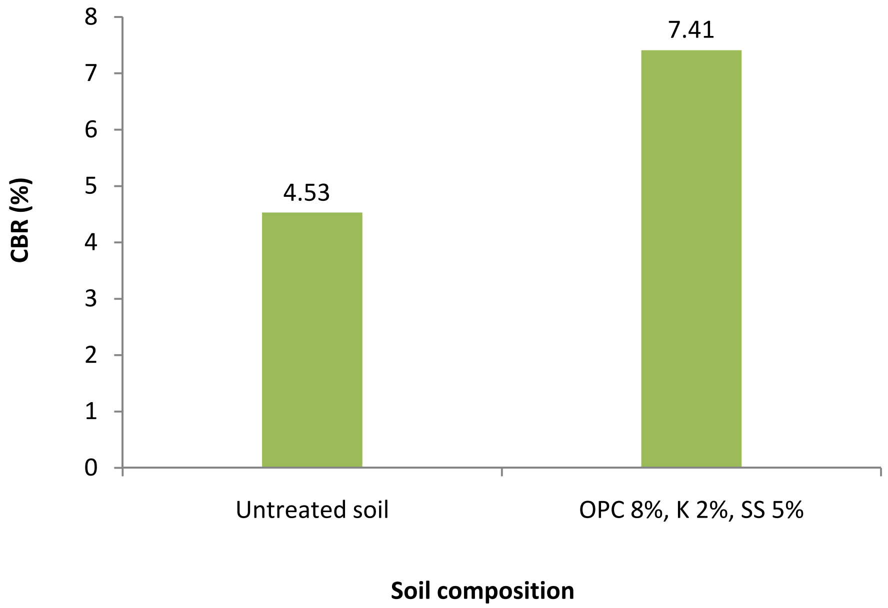

Figure (6): Effect of stabilization on CBR of the soil

Stabilized Soil

The stabilized soil with cement and kaolin was sheared with four different amounts of normal stress; 10.90 kPa, 21.80 kPa, 43.60 kPa and 87.20 kPa, and results were analyzed to obtain the required shear strength parameters. As shown in Figure 3, normal stress increment affected the shear stress. As such, shear stress increased while normal stress was increasing. For the stabilized clay with kaolin, peak strength was not observed. Thus, soil is stated to be in normal consolidation condition. Therefore, the soil specimen exhibited contraction behavior as evident in Figure 4. Comparing the test results of stabilized soil with kaolin and that of untreated clay could reveal that binder composition of OPC 8%, K 2% and SS 5% has improved the shear strength of the soil specimen by almost 1.93-folds. Herein, fine particles of kaolin filled up the pore spaces of the cemented clay and thus the soil matrix was reinforced, strengthened and closely packed as the hydration and pozzolanic products are formed during cemented hydrolysis (Wong et al., 2013).

Unconfined Compression

According to ASTM D 2166, the purpose of unconfined compression test is to measure the shearing resistance of cohesive types of soil which may be undisturbed or remolded specimens. The unconfined compressive strength is defined as the maximum unit stress obtained within the first 20% strain. Based on the results of unconfined compression test, the values of unconfined compressive strength and vertical strain were obtained. The graphical relationship of unconfined compressive strength *versus* vertical strain for both untreated and stabilized soil specimens is shown in Figure 5. By inspecting Figure 5, it can be observed that there is a significant improvement in the unconfined compressive strength of the stabilized test specimen with cement 8%, kaolin 2% and silica sand 5%. This points out that the unconfined compressive strength of the stabilized soil specimen was improved by almost 1.33-folds. 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-folds. This great improvement is due to the addition of more cement content to clay and dynamic compaction energy that yielded greater density of the stabilized soil.

CBR (California Bearing Ratio)

The effect of stabilization of soft clay at optimum moisture content and maximum dry density with cement and kaolin on CBR value is shown in Figure 6. Based on Figure 6, addition of cement and kaolin to soil specimen improved the CBR of the soil. However, the effect of stabilization on CBR is not significant. 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 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 soil were determined 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.

CONCLUSIONS

Effect of cement, kaolin and silica sand on mechanical behavior of compacted clay was investigated in this paper. The following conclusions are drawn from the results of this study.

1. Based on the results of standard Proctor and direct shear tests, ordinary Portland cement was partially replaced with 2% kaolin. Therefore, input cement was saved due to partial replacement of ordinary Portland cement with 2% kaolin.
2. The optimal mix design of stabilized soil was obtained for binder composition of OPC 8%, K 2% and SS 5%.
3. Based on the filler and pozzolanic effect of kaolin, pore spaces of the stabilized soil were covered; thus, matrix of the soil was reinforced and mechanical behavior of the stabilized soil improved.
4. It was found that the shear strength of the stabilized soil specimen containing 2% kaolin is 1.93-folds

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 1.33-folds greater than that of untreated soil specimen.
6. As for the CBR value, it was found that the CBR value of stabilized clay increased slightly in comparison with the CBR of untreated soil specimen.

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

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