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Assessment of Strength Development in Stabilized Soil with CBR Plus and Silica Sand

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Abstract: This paper investigates the potential use of a nano polymer stabilizer, namely CBR PLUS for stabilization of soft clay and formulation of an optimal mix design of stabilized soil with CBR PLUS and silica sand. The highway settlements induced by the soft clay are problematic due to serious damages in the form of cracks and deformation. With respect to this, soil compaction and stabilization is regarded as a viable method to treat shallow soft clayey ground for supporting highway embankment. The suitability of stabilized soil was examined on the basis of standard Proctor compaction, California Bearing Ratio (CBR), unconfined compression, direct shear and permeability falling head tests. Furthermore, the chemical compositions of the materials were determined using X-Ray Fluorescence (XRF) test. The objectives of this paper are (i) to stabilize the compacted soil with CBR PLUS and silica sand in the laboratory; and (ii) to evaluate the strength and CBR of the untreated and stabilized soil specimens. It was found that the optimal mix design of the stabilized soil is 90% clay, 1% CBR PLUS, 9% silica sand. It is further revealed that, stabilization increases the CBR and unconfined compressive strength of the combinations by almost 6-fold and 1.8-fold respectively. In summary, a notable discovery is that the optimum mix design can be sustainably applied to stabilize the shallow clay without failure.

Keywords: CBR PLUS, Clay, Silica Sand, Permeability, Strength

Introduction

Soil stabilization 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). A land-based structure of any type is only as strong as its foundation. This implies that, soil is an essential and critical element influencing the success of a construction project. Soil is either part of the foundation or one of the raw materials used in the construction process. Therefore, understanding the engineering properties of soil is crucial to obtain strength and economic permanence. Soil stabilization is the process of maximizing the suitability of soil for a given construction purpose (Jihwan *et al*., 2015). A novel approach to stabilize the clay is to use the CBR PLUS as a liquid soil stabilizer in the compacted and stabilized soils. It is worth noting that research works on the application of CBR PLUS in soft clay stabilization are relatively scarce. According to Taherkhani *et al*. (2012), CBR PLUS is an ionic synthetic organic thio compound, with surface active properties. It transforms the hydrophilic nature of the clay material into a hydrophobic nature due to the formation of oily layers on the surface of soil and clay particles. It is obtained from beetroots and specially manufactured, for the purpose of treating natural soils by improving the permeability, density and strength of the stabilized soil. CBR PLUS is a soluble adsorbed water displacing ionic additive which can make a poor quality in-situ soil resist the effects of rain, so as to enable the road to be used at all times by light traffic without the need to hauling in and placing of a gravel layer (North America Inc, 1999a). Aside from engineering properties of CBR PLUS, it is non-toxic, non-hazardous and non-flammable (Bagombeka, 2000; Ziaie Moayed and Allahyari, 2012; North America Inc, 1999b). Ziaie Moayed and Allahyari (2012) have documented that CBR PLUS is able to stabilize the various types of soils containing some clay particles. Radgohar *et al*. (2010) further stipulated that stabilization of clay with polymer could improve the unconfined compressive strength of the stabilized soil. The use of micro and nanoscale additives such as CBR PLUS now becomes a matter, which deserves serious consideration (Naeini and Ziaie Moayed, 2009; Naderinia and Naeini, 2009; Naderinia, 2010). As demonstrated above, utilization of CBR PLUS to stabilize a wide spectrum of soils ranging from silty sands to gravel containing some clay particles (i.e., soil with cohesive properties) has been proven to be efficient in providing additional bearing capacity and strength. This paper focuses on finding the most viable mix design of relevant materials that can effectively stabilize the shallow clay. In relation to this, the approach of mixing the soft clay with the materials is relevant in geotechnical industry. Considering the fact that it is economical and sustainable to apply the selected mixtures of the materials to improve the soil. The materials that are investigated in this study for the soil improvement are CBR PLUS and silica sand. CBR PLUS is chosen for the study because it is regarded as a nano polymer stabilizer which can contribute to the enhancement of the soil strength and bearing capacity. On the other hand, CBR PLUS is an environmentally-friendly material which could reduce dust on unpaved roads. Previous studies have proven that CBR PLUS can be used to stabilize clayey soils with ion exchange solution (Ziaie Moayed and Allahyari, 2012). It is notable that the main focus of the research is to stabilize the compacted clay with CBR PLUS and silica sand in the laboratory and optimize the additives for the clay improvement. To this end, the CBR PLUS/optimum water mixture (CBR PLUS in low dosage) was mechanically mixed with soil in a soil mixer. With regard to this, the standard Proctor compaction test could be reliably carried out to gauge the dry density of the stabilized soil. The results of standard Proctor compaction tests were used in preparation of permeability falling head, unconfined compression, direct shear and CBR test specimens. The main objective of this study is to evaluate the strength and CBR of the untreated and stabilized soil specimens.

Laboratory Investigation

Soil Sample

For the purpose of the present study, 10 soil samples from a depth of 2 m below the ground surface occurring in the Taman Wetlands area in the state of Putrajaya were taken, which are quite representative of the whole region, have been sampled. The experimental program was initiated by transporting the soil samples to the Soil Mechanics Laboratory at UNITEN. Based on Unified Soil Classification System (USCS), the soil was classified as silty sandy CLAY. The natural soil sample has following properties: Specific gravity = 2.46, liquid limit = 56%, plastic limit = 24%, plasticity index = 32%, pH = 7.1, optimum moisture content = 16.32% and maximum dry density of 1.782 ton/m^3. The particle size distribution curve of the soil sample is illustrated in Fig. 1. Based on Fig. 1, the natural soil sample composed of 62% clay, 38% silt and sand. A 62% clay makes the soil sample suitable for stabilizing with CBR PLUS. The X-ray Diffraction (XRD) technique was used to determine the natural soil mineralogical composition. It is revealed that Taman Wetlands soil consist mainly of quartz and subordinate kaolinite. This implies that the natural soil has a low swelling potential. Also, its clay fraction being composed of a significant amount of illite. Furthermore, the chemical compositions of oven dried soil and silica sand by percentage weight, of the total chemical composition from X-Ray Fluorescence (XRF) tests are specified in Table 1. Based on Table 1, a chemical composition of 89.0011% SiO_2 affirms that quartz is the major constituent of the silica sand. By inspecting Table 1, it can be observed that in the oven dried clay the sum of AL_2O_3 and SiO_2 is 76.6873%. This is attributed to a very high amount of clay minerals in the soil sample.

Silica Sand

For the purpose of particle grading modifier, silica sand was collected from Civil Engineering laboratory of UNITEN. The particle size distribution curve of the silica sand is plotted in Fig. 2.

CBR PLUS

CBR PLUS was prepared from Iran Polymer Company. The mechanism of CBR PLUS which functions as oily layers on the surface of clay particles and removes adsorbed water is indicated in Fig. 3.

The physico-chemical properties of the CBR PLUS are tabulated in Table 2. According to North America Inc., CBR PLUS is a highly concentrated liquid, of which 100 liters treats between 4000 to 20000 m^2 of soil to a depth of 15 cm when diluted with water. CBR PLUS is available in the form of chocolate-brown viscous fluid with very complicated cells. Each cell includes a tail and head. Basically, the head of a cell is hydrophilic and the tail of it is hydrophobic (Fig. 4). Since CBR PLUS is a strongly concentrated liquid, the rate of reduction in adsorbed water from the soil particles is of interest to practice.

Mix Design

The proportions of soil, CBR PLUS and silica sand used in the mix design for the fabrication of test specimens are summarized in Table 3. In order to stabilize the soil sample, 5 mixes with various dosages of CBR PLUS and silica sand were prepared. CBR PLUS was ranged to be 0 to 1% by weight of the optimum water content. It is noticeable that 0 to 1% CBR PLUS for the soil stabilization purpose is commonly used by (Taherkhani *et al*., 2012; Ziaie Moayed and Allahyari, 2012). Silica sand was designed to be between 0 to 10% by dry weight of the natural soil sample, simultaneously CBR PLUS varied from 0 to 1%. The natural soil sample without CBR PLUS and silica sand was also investigated. The trial mix designs of the soil sample and additives are specified in Table 3.

Table 1: XRF results of the natural soil sample and silica sand

	Weight (%)	
Oxide compound	Silica sand	Oven dried soil
Al_2O_3	5.1661	21.4238
SiO_2	89.0011	55.2638
SO_3	0.1421	-
K_2O	1.4632	6.8600
CaO	0.3372	1.6275
TiO_2	1.4029	2.4714
Fe_2O_3	1.0301	12.2232
Others	1.4573	0.1303

Table 2: Physico-chemical properties of CBR PLUS (Ziaie Moayed and Allahyari, 2012)

Appearance	Chocolate Brown viscous fluid
Odour	Sulphurous Odour
Physical State	Viscous Fluid
Freezing Point (°C)	<-10°C
Boiling Pint (°C)	100°C
pH	0.9
Specific Gravity (G_s)	0.94
Coefficient Water/Oil	100% water soluble

Table 3: Trial mix designs under study

Test specimen	Mix designation	CBR PLUS in 1 lit water (g)
Natural soil sample	Untreated soil	0.0
Stabilized soil	0% CBR PLUS, 10% Silica sand	0.0
	0.25% CBR PLUS, 9.75% Silica sand	1.5
	0.5% CBR PLUS, 9.5% Silica sand	3.0
	0.75% CBR PLUS, 9.25% Silica sand	4.5
	1% CBR PLUS, 9% Silica sand	6.0

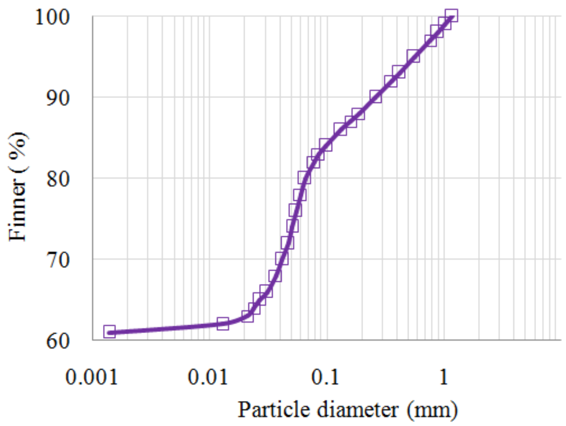

Fig. 1: Particle size distribution curve of the natural soil sample (Mousavi and Wong, 2015)

Specimen Preparation

The soil sample was oven dried at the temperature of 105±5°C, then cooled at a room temperature and sieved (passing a 2 mm sieve size) to remove the clumps and finally homogenized. In order to stabilize the soil sample with CBR PLUS and silica sand, CBR PLUS was slowly diluted with optimum water content in a mixer. Later, solution was added to the soil sample containing silica sand and further mixing durations were applied on the mixture so as to ensure a satisfactory homogeneity. Then, the soil admixture was thereafter sealed in plastic bags for 28 days as recommended by (Taherkhani *et al*., 2012). The test specimens were then left at ambient laboratory temperature (25±1°C). During the time, the density of the test specimens was monitored by measuring the volume of the specimens using a caliper (±0.001 mm). Moreover, the moisture content of the soil specimens was monitored by weighing (±0.001 g). It should be noted that, little variation in moisture content and density were observed. Over time, a pronounced impact of optimum moisture content and CBR PLUS dosage in a way that CBR PLUS removes the adsorbed water from soil particles and leads to the flocculation of the particles thus stabilizes the soil specimen. Generally, the prolonged duration (28 days) helped to a continuous formation of stabilization that strengthened the soil specimens.

Methodology

For the purpose of standard Proctor compaction test, the supplied 28-day soil admixture was tamped in a compaction mould in three equal layers. Each soil layer was compacted for 25 blows similar to that of conducted by Mousavi and Wong (2015). To prevent moisture loss, compacted soil specimens were sealed in plastic bags. The unconfined compression test specimens were trimmed from the circular compaction test specimens. The height of the specimen is corrected to 100 mm and Unconfined Compression (UC) tests were carried out as described in ASTM D2166-06. It should be noted that the UC test specimens were designed with a height to diameter ratio of 2. The UC tests were carried out at a constant vertical displacement rate of 1 mm/min. Other than Proctor and UC tests, permeability falling head, direct shear and CBR tests also were carried out. The falling head test was applied to determine the coefficient of permeability of both untreated and stabilized soil specimens. The test was conducted at room temperature in accordance with ASTM D5084-03. Direct shear tests were applied on soil specimens as stated in ASTM D3080-04. For this purpose, the square soil specimen with dimension of 60 mm and height of 30 mm was trimmed from the circular compacted soil specimen. The rate of shearing was adjusted on 0.5 mm/min. The test specimen was sheared under the application of 10.90, 21.80, 43.60 and 87.20 kPa normal stresses.

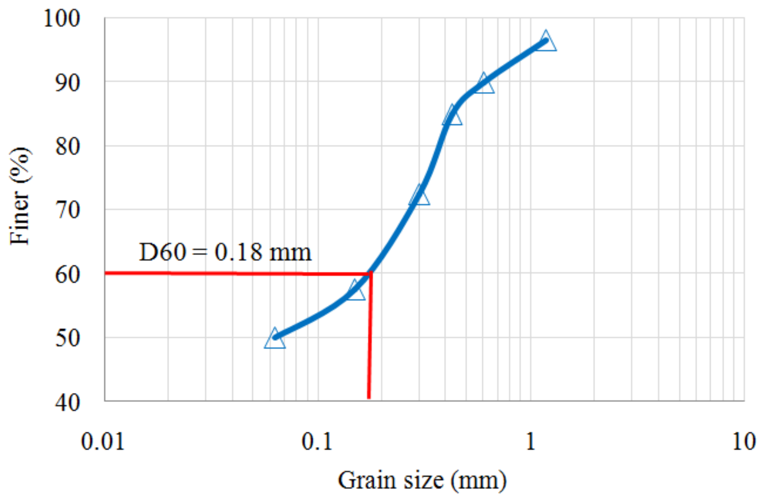

Fig. 2: Particle size distribution curve of the silica sand

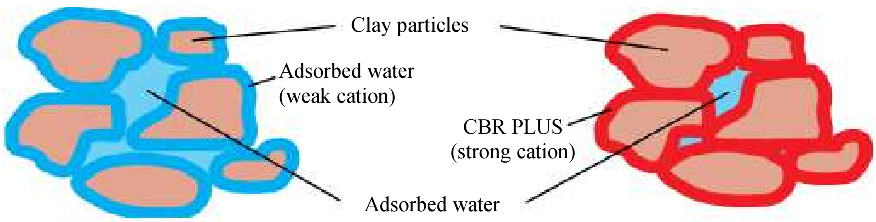

Fig. 3: Mechanism of CBR PLUS (Ziaie Moayed and Allahyari, 2012)

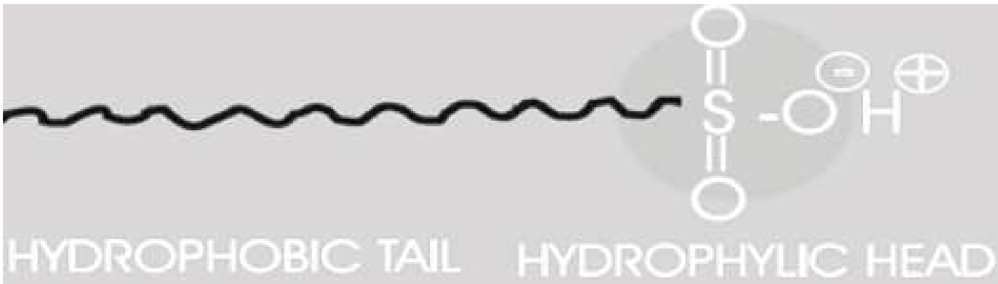

Fig. 4: A CBR PLUS cell (Taherkhani *et al*., 2012)

To evaluate bearing capacity of the soil specimens, CBR tests were performed as described in ASTM D1883-14. Note that, all laboratory tests were conducted according to the ASTM standard and all the test specimens were tested at optimum water content and maximum dry density.

Results and Discussion

Plasticity Behavior

Atterberg limits of clayey soils are indices of the amount of clay particles and mineralogical composition. Typically, higher plasticity indices of clay are associated with a greater quantity of clay particles and their surface activity. From Fig. 5, an improvement of index properties of the stabilized soil for up to 1% CBR PLUS addition with a decrease in Plasticity Index (PI) from 31 to 14% can be seen.

pH

Effect of stabilization with CBR PLUS and silica sand on pH of stabilized soil specimens are illustrated in Fig. 6 The pH value of stabilized soil admixture corresponding to 1% (6 g) CBR PLUS dosage was found to be 7.3. Based on Fig. 6, there is a trend of progressive decrease in the pH values of the stabilized soil admixtures with increasing CBR PLUS content. From Fig. 6 it can be seen that all the stabilized soil specimens exceeded the minimal required pH of 7. Therefore, the stabilized soil specimens are in alkaline condition.

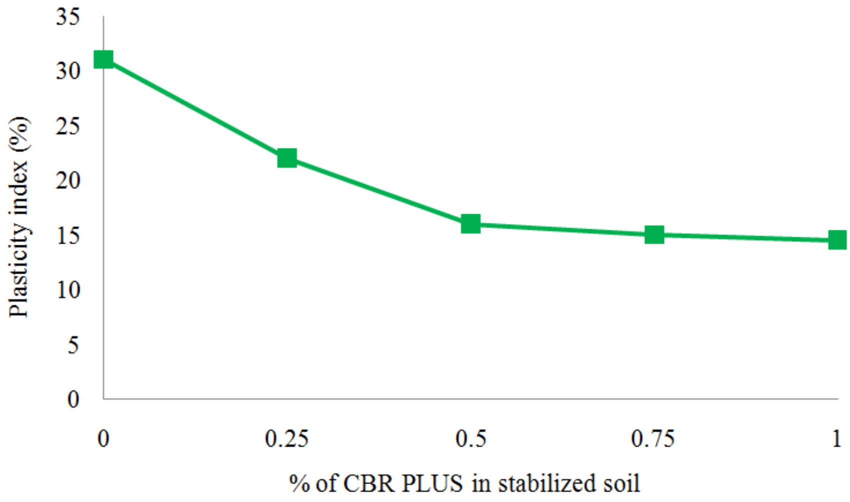

Fig. 5: Plasticity index of the stabilized soil specimens

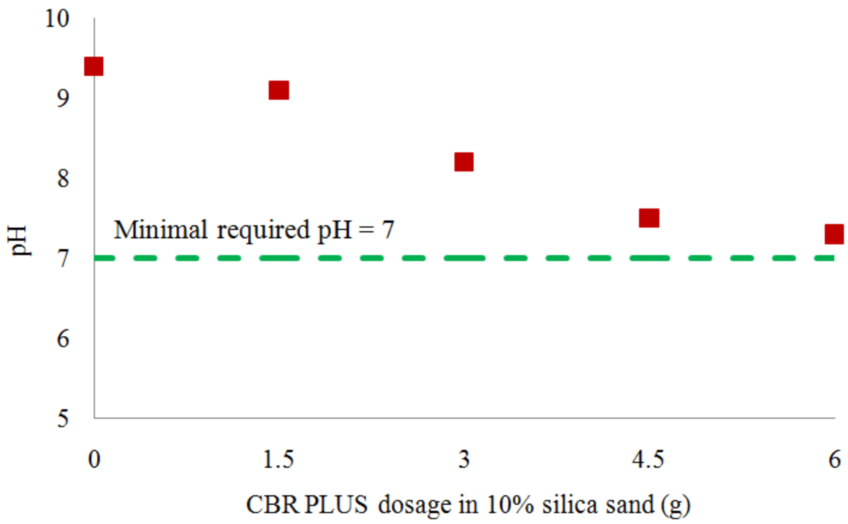

Fig. 6: Effect of stabilization with CBR PLUS and silica sand on pH of stabilized soil specimens

Standard Proctor Compaction

Effect of stabilization with CBR PLUS and silica sand on compact ability of the untreated and stabilized soil specimens are illustrated in Fig. 7. Based on Fig. 7, maximum dry density of the soil specimens increased with increase in CBR PLUS dosage. It is shown in Fig. 7 that the highest maximum dry density is determined to be 1.993 ton/m^3, which is corresponding to the stabilized soil with 1% CBR PLUS and 9% silica sand. This positive result implies that CBR PLUS functions as an oily layer on the surface of soil particles eliminating the adsorption of water, which is chemically bound with the soil particles and this facilitates the compaction, thus increasing the interlocking of soil particles as well as maximum dry density (Ziaie Moayed and Allahyari, 2012). Meanwhile, the steady decrease in the optimum moisture content with increasing CBR PLUS content is attributable to the ability of the CBR PLUS to induce less water sorptivity in the test specimen at its maximum dry density. After judging the trend of maximum dry density and optimum moisture content of the test specimens, it was decided to further evaluate the effect of CBR PLUS on the untreated and stabilized soil specimen with 1% CBR PLUS and 9% silica sand under laboratory direct shear, unconfined compression and CBR tests.

Coefficient of Permeability

The permeability falling head test was applied on 100 mm diameter and 121 mm height of the untreated and stabilized soil specimens. Results of falling head

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tests are indicated in Fig. 8 and 9. From Fig. 9, it can be observed that the permeability of the soil specimen without CBR PLUS (i.e., 9% silica sand) was drastically increased. This implies that the addition of more silica sand imposes more porous and higher permeability. The k_v values of stabilized soil specimens with 0, 0.25, 0.5, 0.75 and 1% CBR PLUS were found to range from 0.007 to 0.00001 cm/day. Such a range of rates of permeability is relatively vast, which implies that addition of CBR PLUS significantly alter the hydraulic conductivity of the soil. Similarly, a study conducted by Taherkhani *et al*. (2012) on stabilization of local soil with CBR PLUS supports the present results. Taherkhani *et al*. (2012), have found that the k_v value at 20°C of local soil is 0.008 cm/day. It is documented by Taherkhani *et al*. (2012) that the permeability rate of stabilized soil with 0.25, 0.5 and 0.75% CBR PLUS is almost zero. Thus, such rate of permeability is very close to that of investigated in this research work.

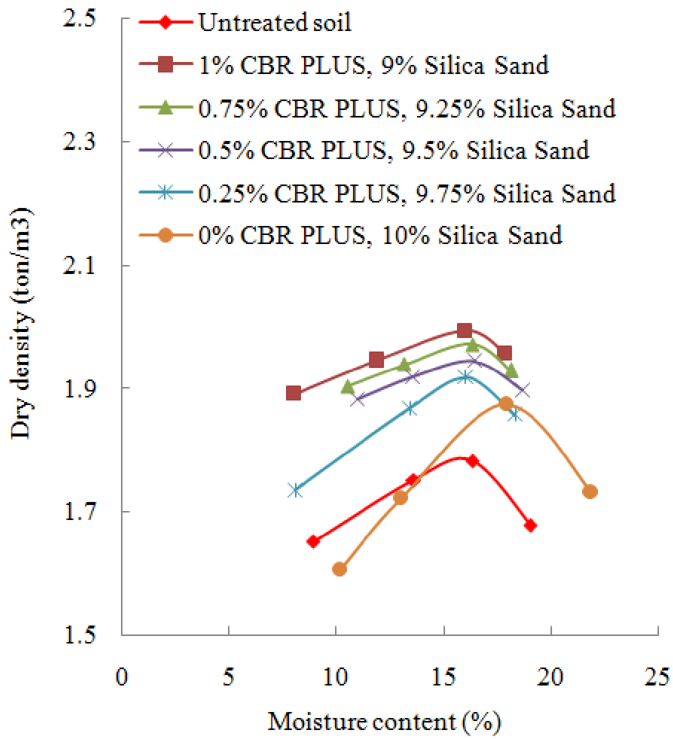

Fig. 7: Dry density-moisture content relationships of 28-day untreated and stabilized soil

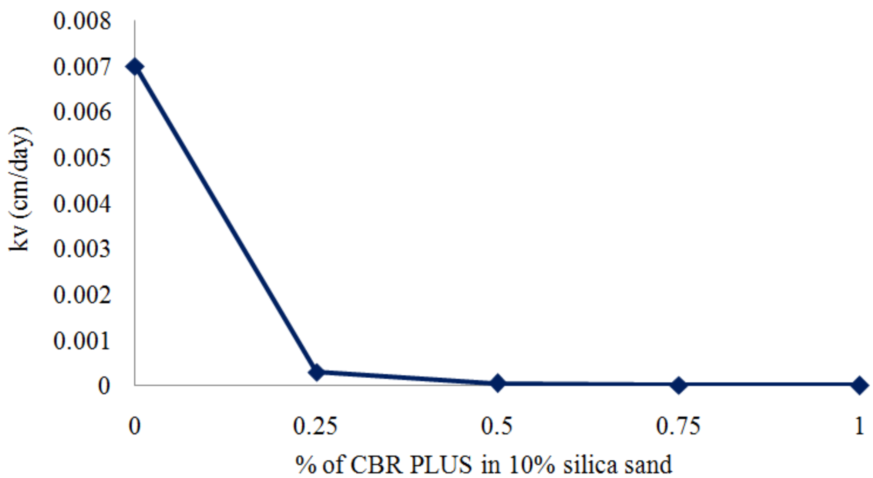

Fig. 8: Variation of coefficient of permeability of stabilized soil specimens

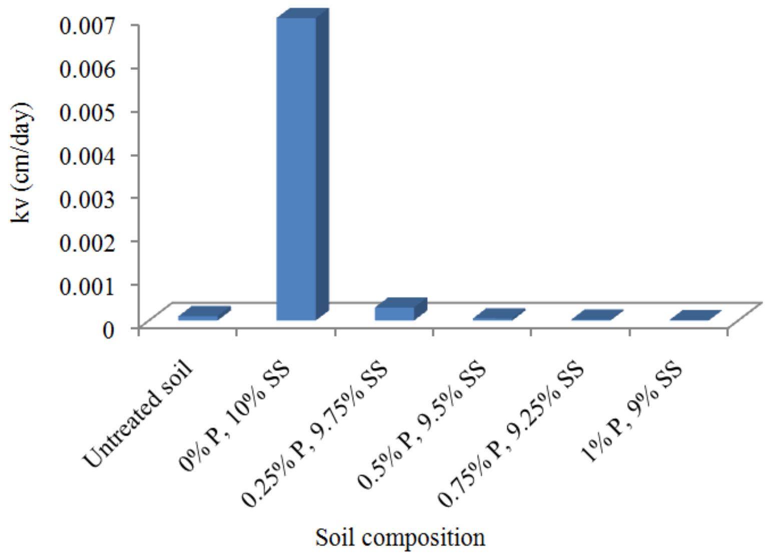

Fig. 9: Effect of stabilization on coefficient of permeability Notes: P is CBR PLUS and SS is silica sand

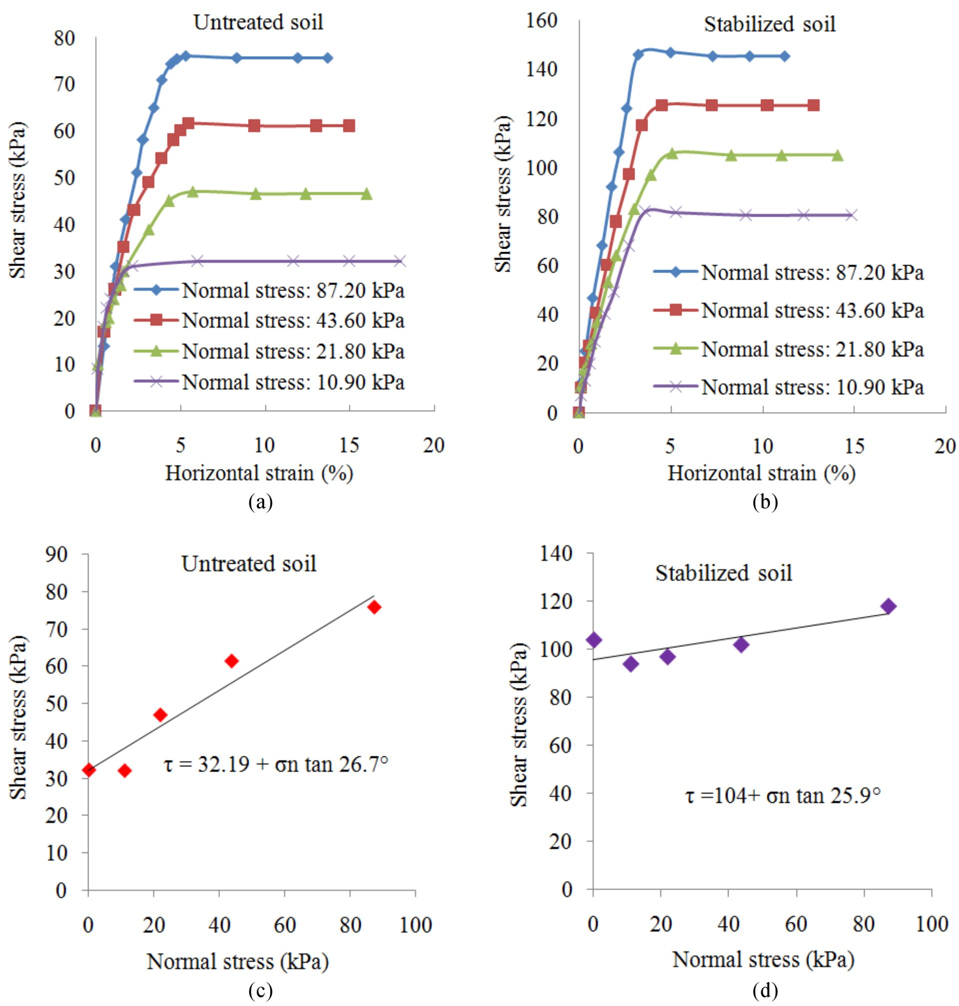

Fig. 10:(a and b) Shear stress-Horizontal strain relationships of untreated and stabilized soil, (c and d) Strength envelope line of untreated and stabilized soil respectively

Direct Shear

In order to evaluate shear strength parameters, the untreated and stabilized soil with 1% CBR PLUS and 10% silica sand were sheared under four normal stresses of 10.90, 21.80, 43.60 and 87.20 kPa. The corresponding shear stress-horizontal strain curves for the test specimens were plotted as shown in Fig. 10a and b. It is observable in Fig. 10a and b that there was an obvious trend of shear stress increase with horizontal strain before failure. Indeed, the increase of the peak shear stress was very much dependent on the increase of its normal stress. Besides, Fig. 10c and d indicates strength envelope, which was obtained from the direct shear tests. The respective cohesion and internal friction angle of the stabilized soil were found to be 104 kPa and 25.9°. Comparing the results of stabilized soil with those of untreated soil, it could be concluded that the test specimen with a mix design of 1% CBR PLUS and 9% silica sand increased its shear strength by almost 1.9-fold. This is partially attributed to the CBR PLUS that surrounded the soil particles by forming oily layers on the surface, thus strongly increased cohesion of the stabilized soil.

Unconfined Compression

The relationships between unconfined compressive strength and vertical strain of the untreated and stabilized soil specimens are established in Fig. 11. The unconfined compressive strength of untreated and stabilized soil with 1% CBR PLUS and 9% silica sand was found to be 228 and 421 kPa respectively. This provides an indication that the stabilized soil specimen had tremendous improvement in term of unconfined compressive strength. The binder composition of the stabilized soil specimen with 1% CBR PLUS, 9% Silica sand enhanced the unconfined compressive strength by almost 1.8-fold in comparison to that of the untreated soil. This is attributed that CBR PLUS played a significant role in the enhancement of flocculation and soil particle stability. This leads to increase in the electrostatic attraction among the soil particles due to the adhesivity of CBR PLUS. Thus, the strong bond between the soil particles could be formed which increased the strength of the stabilized soil.

The vertical strains corresponding to the untreated and stabilized soil specimens with the binder composition of 1% CBR PLUS and 9% silica sand were determined to be 17 and 15% respectively. Therefore, untreated and stabilized soil specimens both exhibited a ductile behavior at failure under unconfined compression due to the plasticity of the clay and CBR PLUS addition. It is noticeable from Fig. 11 that the pattern of increase in unconfined compressive strength of the stabilized soil over axial strain can be linked to its continuous development of modulus of elasticity (Fig. 12). This provides an indication that the higher the unconfined compressive strength of the stabilized soil with a binder composition of 1% CBR PLUS, 9% Silica sand the higher is its modulus of elasticity which implies that it has a greater stiffness.

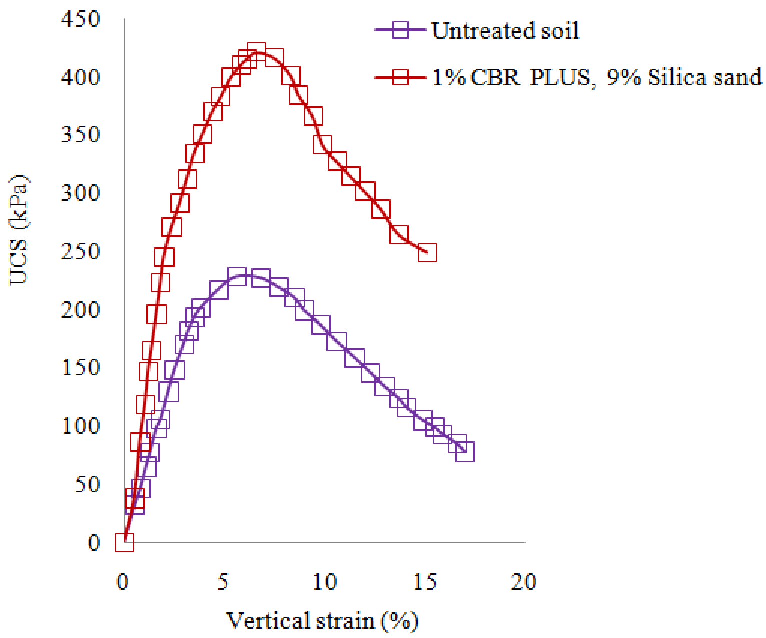

Fig. 11: Unconfined compressive stress-vertical strain relationships of the untreated and stabilized soil

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CBR

The graphical relationships between load and penetration of the test specimens are illustrated in Fig. 13. From Fig. 13 it can be seen that the stabilized test specimen with a binder composition of 1% CBR PLUS and 9% silica sand positively increased the soil bearing capacity. This points that, the surface contact areas of soil particles exposed to an extremely thin layer of CBR PLUS and allowed water, to be driven out of the soil matrix. Therefore, the stabilized soil can be compacted to a higher density. This strengthened the stabilized soil and thus the amount of load for penetration decreased, which resulted in the CBR increase. Besides, the CBR value of the soil specimens decreased while PI of the soil increased. It can be stated that, as the PI of the soil increases, the optimum water content also increases, hence the maximum dry density and bearing capacity of the soil decline. The mean CBR values corresponding to the untreated and stabilized soil were determined to be 4.5 and 28% respectively. On the basis of additive dosage, the quantity of additive must be sufficient to achieve a threshold effect for the soil stabilization to be effective (Wong *et al*., 2013). Based on the correlation between unconfined compressive strength and CBR reported by (Purwana and Nikraz, 2013; Khalid *et al*., 2014), the minimal required CBR of the soil specimens should be about 25%. A CBR value that exceeded the minimal required CBR of 25% was achieved by the stabilized soil with 1% CBR PLUS and 9% silica sand (Fig. 14). A comparison can be carried out between the results of the present work and those of reported by (Taherkhani *et al*., 2012). The difference between the results is due to the nature of the soil types, their properties and different additive dosages.

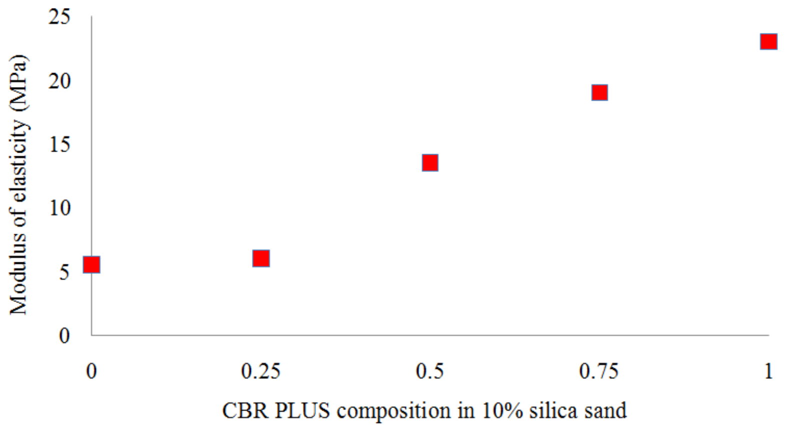

Fig. 12: Implication of modulus of elasticity (E) of stabilized soil specimens with CBR PLUS

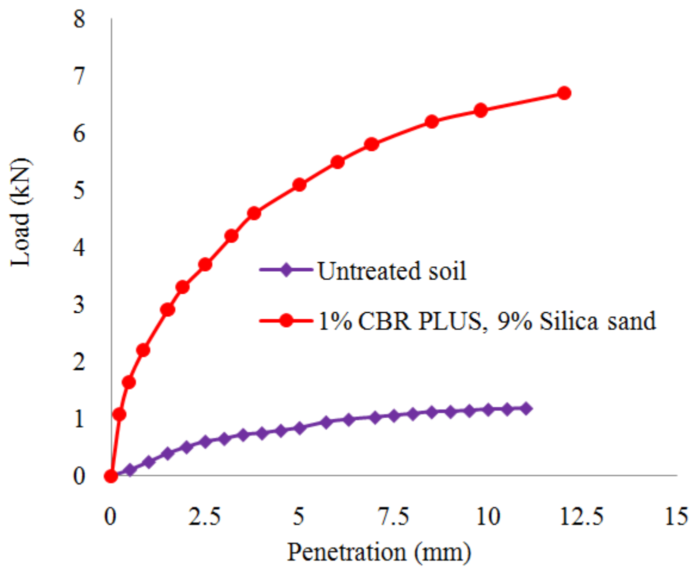

Fig. 13: CBR of the soil specimens

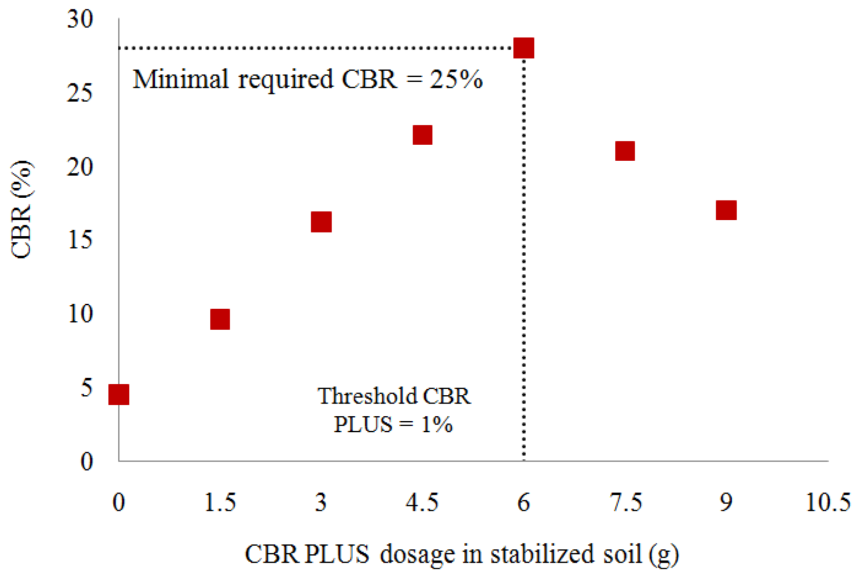

Fig. 14: Effect of CBR PLUS dosage on CBR of the stabilized soil

Conclusion

CBR PLUS affects the index properties by improving the workability of the soil sample and its sensitivity to moisture. From the results of this research, the following conclusions are drawn:

- The compacted soil was successfully stabilized with CBR PLUS and silica sand in the laboratory. The optimal mix design of the stabilized soil was found to be 1% CBR PLUS and 9% silica sand
- The stabilized soil with CBR PLUS and silica sand compacted to a better particle-interlock state under standard Proctor compaction. The compacted soil stabilized at the optimal mix design has the highest maximum dry density of 1.993 ton/m^3
- An abrupt decrease was observed for the coefficient of permeability with increased CBR PLUS dosage
- There is a significant improvement in term of strength of the soil stabilized at the optimal mix design. The shear strength of the stabilized soil is 1.9 times greater than that of untreated soil
- The unconfined compressive strength and CBR of the stabilized soil increased by about 1.8-fold and 6-fold respectively as compared to that of untreated soil

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Author's Contributions

Seyedesmaeil Mousavi: Participated in all experiments, coordinated the data-analysis, designed the research plan and has written the manuscript.

Aliakbar Karamvand: Contributed the mouse work.

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