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Sawdust Effect on Compressibility and Shear Strength Characteristics of Highly Organic Clay

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ABSTRACT

Organic soils are known for their low shear strength and high compressibility, making them unstable and unsuitable for supporting foundations with instability problems such as local sinking, development of slip failure, excessive settlement, and bearing capacity failure. Thus, such soils need improvement prior to construction to suit the infrastructure projects. Several improvement techniques are available depending on the thickness of the organic deposit, type, and characteristics. The stabilization technique is one method that is considered economical, functional, and environmentally friendly; it is the process of changing the chemical properties of soil by adding stabilizers in wet or dry conditions such as lime, fly ash, cement, sawdust, or sawdust ash to increase the shear strength, decrease the compressibility and permeability of the soil. In the current study, an experimental effort investigates the effect of mixing sawdust with highly organic clays. In the presence of moisture, sawdust, widely available and economical, reacts chemically, forming cementations compounds that improve soils' strength and compressibility properties. Highly organic clay samples from Kafr El Sheikh Governorate, Egypt, were mixed with 5 % cement and varying percentages of sawdust by weight. Samples are cured for seven days before conducting shear strength and compressibility tests. The tests include laboratory shear vane, direct shear, and one-dimensional oedometer tests. The results provide insight into the use of sawdust in improving the strength and deformation properties of the tested organic clay.

Keywords: *Organic clay, Stabilization, Sawdust, Cement, Direct shear, Oedometer, Vane Shear Test.*

1. Introduction

Organic soils and Peat deposits represent the extreme form of soft soil. These deposits are formed from the decomposition of the remains of dead plants that have accumulated partially or underwater with a lack of oxygen for thousands of years [1]. Peat soil contains more than 75 % organics, while organic silt and clay are the soil with 25% or less organics (Tentative ASTM Standard).

In Egypt, organic soil deposits extend as a belt from east to west, around and between the two branches of Nile River in Dakahlia, south Domyat, north Sharqia, north-east of Gharbia, middle and west of Kafr-Elsheikh, and north-east of Bohira governorates, according to the pioneering work reported in the Geotechnical Encyclopaedia of Egypt [2].

Organic deposits are mainly of buried nature, which are thought to be developed because of the sea changes after the last ice sheets retreat in areas along and around the old Nile River branches. In addition, organic deposits exist within the thick, soft clayey deposits of the Delta region as interbedded layers of varying thicknesses and at varying depths [2].

Organic soil is a problematic deposit and needs to be improved/ stabilized before construction due to having poor properties such as low shear strength, high compressibility, high rate of creep, and low bearing capacity, which may experience bearing capacity failure and excessive settlement [1, 3]. The chemical stabilization technique is a common method used in improving the mechanical properties of soil.

Stabilization of weak soils using a chemical additive in wet or dry conditions improves their properties through chemical reactions. It helps to increase the bearing capacity strength and decreases settlement and lateral deformation [4].

Studies investigate stabilizing organic soils with chemical additives such as lime, fly ash, Portland cement, etc. [5, 6]. Nevertheless, increasing the stabilization materials price would increase the construction cast. Therefore, to overcome this problem, numerous studies investigated the influence of waste materials such as sawdust, sawdust ash, rice husk, and rice husk ash as a stabilizing agent in improving organic soils [7, 8, and 9].

In Egypt, sawdust is considered one of the agricultural wastes produced in large quantities from wood cutting factories in several sizes and shapes.

Agricultural scientists are reluctant to stabilize weak soils with sawdust because it is considered a required form of organic matter, its slow decomposition rate, and its temporary depression of nitrates, which is the main objection to its use [10].

Despite these disadvantages, applying sawdust to weak soils may be an excellent way to help in improving its engineering properties because, in the presence of moisture, sawdust reacts chemically, forming cementations compounds that will enhance the strength and compressibility properties of soils [10].

Limited research has investigated the influence of sawdust as fibre reinforcement material in organic soils. Sawdust is added to the soil as a filler to increase the number of soil particles and reduce the void ratio without any chemical reaction with the soil [7, 8].

This research aims to study the influence of adding various percentages of sawdust on the shear strength and compressibility of organic clay soil with 5% Portland cement.

2. Materials

2.1 Study Area

Undisturbed and disturbed samples were collected from 7.0 m -8.50 m depth from the ground surface from the Sidi Salem area – Kafr Elsheikh Governorate- Egypt. Groundwater table was found at 3.00 m below the ground surface, so the soils are fully saturated. Samples were classified by sight as organic soil since they have a dark brown colour with visible organic contents such as tree trunks and branches. Organic samples were stored in wooden boxes and transported to the laboratory.

2.2 Sawdust

Sawdust from a local carpentry workshop in Cairo was used as an additive in the experimental procedure. Sawdust was passed through a 0.425 mm sieve (ASTM No. 40) and then added to the organic clay soils with various percentages (10%, 15%, and 20%).

Table 1. Essential characteristics of natural organic clay soils

Parameter	**Value**
(%Water content (Wc	109
(%Organic content (Oc	22.8
pH value	7.2
($_s$G) Specific gravity	2.16
($_b\gamma$) Bulk unit weight ^{3}kN/m	11.44
(Liquid limit (LL	138.50
(Pl) Plastic limit	84.86
(PI) Plasticity index	53.64

2.3 Preparation of soil-cement- sawdust mixtures

The natural organic soil sample was transferred to the mixer's metal bowl and placed under the mixer's mechanical mixing hook. A mixing speed setting of Level 1, or 60 RPM, was used for 10 minutes to homogenize the organic clay soil before binder addition. Then, Cement – Sawdust was added to the untreated organic clay soil. The mixer was turned off first to add the first batch of binder (5% cement only). Then the mixture was allowed to mix for one minute at the speed of Level 1. After one minute, the second batch was added with 10% sawdust with the same mixing procedure until all binders were added. During the mixing intervals, the side of the mixing bowl was scraped with a spatula to ensure consistent homogenization of the mixture. After adding the fourth batch of sawdust, the mixing speed was switched to Level 2 to homogenize the mixture further. After thoroughly mixing the soil, it was melded into a ball by hand with a diameter of approximately 60 mm. The soil ball was dropped into the tube, and a nail hammer was used to compact the ball 30 times. This action will puncture air holes within the soil to facilitate pressure compaction while also applying force to the soil. During storage, the specimen was subjected to a dispersed vertical pressure of 18 kPa utilizing an iron cylinder. This procedure simulated the field condition after mixing was conducted in the field [11, 12].

2.4 Water Curing

A filter paper was taped over the bottom of the plastic tube to permit the organic clay specimen to take up water during storage. The stabilized specimens were then placed in a box to store specimens vertically. The bottom of the tray was then filled with water to a depth of 50 mm, and the mixture was cured for seven days. This will allow the cement to react with soil to increase the strength properties of the soil. After seven days at room temperature, the specimens were expelled from the tubes, and direct shear test, vane shear test, and oedometer test were performed [12].

3. Physical Properties and Soil Characterization

3.1 Physical Properties

Geotechnical tests were carried out to determine the essential characteristics of the organic soil before stabilization, such as water content, specific gravity, organic content, Atterberg limits tests, and acidity. The basic properties of the organic clay soils are shown in Table1. The water content of the organic clay soil samples was obtained following ECP 202-01 202/2 [13]; the specific gravity (Gs) was determined following ASTM D854-02 [14], and the organic content was obtained following ASTM D2974-00 [15] by using the loss on ignition method (LOI), the acidity was determined by pH meter following ECP 202-01 202/2 [13], and Atterberg limits were determined following 202-01 202/2 [13] by using Casagrande device.

In addition, the particle size distribution of natural organic soil samples was obtained through a combination of wet sieving and hydrometer test following ASTM D422 [16]. In contrast, the particle size distribution of sawdust material was obtained through dry sieving following EPC 202/2 [13]. The particle size distribution of natural organic clay soil and sawdust are represented in Figure (1) and Figure (2) representatively.

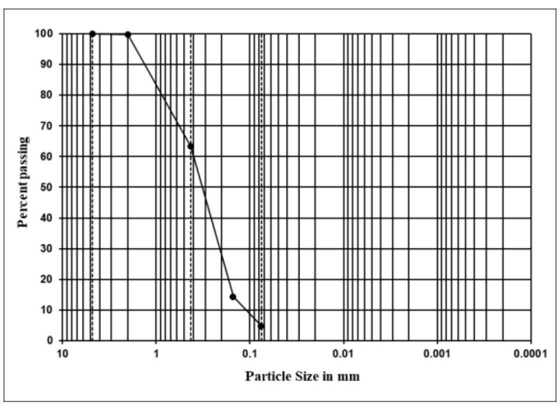

Figure 1- Grain Size Distribution of Natural Organic Clay

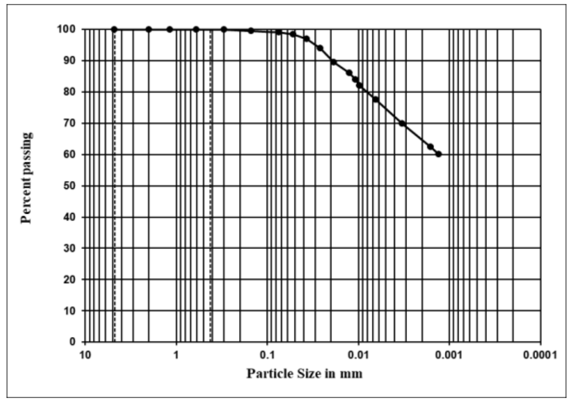

Figure 2: Grain Size Distribution of Sawdust

3.2 Soil Characterization

Basic soil properties with essential organic clay characteristics are summarized in Table 1, where the average specific gravity (G_s) value is 2.16 which is within the range of highly organic clay soils according to the "Tentative ASTM Standard" proposed by the ASTM Subcommittee D18.18 [17, 18].

In addition, the acidity of the natural organic clay soil was determined and had an average value of 7.2. Atterberg limits, the average percentage of liquid and plastic limits are 83.10% and 45.45%, respectively.

The particle size distribution for natural organic clay soil samples indicates that > 96% of the soil is finer than 75 µm, with > 76% in the clay size fraction (<5 µm). In contrast, the particle size distribution for the sawdust sample indicates that > 94% of the soil is finer than 75 µm.

4. Experimental Methods

4.1 Mechanical tests

Mechanical tests were conducted to determine the maximum percentage of sawdust that achieved maximum shearing resistance and lowest compressibility, such as the direct shear test, vane shear test, and oedometer test.

Lab vane shear test was carried out according to ECP 202/2 (2/23/4) [13] to determine the undrained shear strength of natural organic soil, then stabilized organic soil. The vane shear test consists of a thin four-bladed vane at the end that penetrates the undisturbed soil, then the torque or moment is determined by rotating it from the surface until the failure accrues. Undrained shear strength (s_u) is calculated from the following equation:

$$Su = \frac{T}{\pi\left(\frac{H}{2}+\frac{D^3}{6}\right)}$$

Direct shear test was conducted according to (BS1377:Part7:1990) [19] and (ASTM D3080/D 3080M-11) [20] to evaluate the organic clay soil's effective shear strength parameters c′ and ϕ' before and after stabilization. All specimens were prepared in a direct shear metal box with a square cross-section of (60x 60) and a height of 20 mm. Then, they laterally restrained and sheared along a horizontal plane. Three selected vertical forces were applied to the specimen through a loading plate given normal stresses (138.89, 277.78, and 416.67) kPa. Shear stress is gradually applied on a horizontal plane, causing the two halves of the box will be more relative to each other until the specimen experiences failure. After applying each incremental load, the shear displacement of the top half of the box is measured by a horizontal dial gauge.

A dial gauge was used to measure the change in the specimen height due to the movement of the upper loading plate. All tested specimens were fully submerged in deionized water for 24 hours, then consolidated under vertical adequate stress levels for 24 h before shearing. The specimens were sheared with a 0.1 mm/min horizontal displacement rate under drained conditions, slow enough to prevent excess pore water pressures.

As for compressibility of organic clay soil and sawdust, a series of 24 incremental loadings (IL) consolidation tests were performed following ECP 202-01 202/2 [13, 21]. The loading range was 25 – 1600 kPa with a load increment ratio (LIR) = 1.

A seating load of 5 kPa was kept for 24 hours before applying the loading. The consolidation behavior was investigated by studying the parameters such as compression index (C_c), compression ratio (C_r), swelling index (C_s), pre-consolidation pressure ($\sigma`_p$), coefficient of consolidation (C_v), coefficient of compressibility (a_v), and coefficient of volume change (m_v).

5. Results and Discussion

5.1 Atterberg Limits (Oven-dried)

Figure (3) shows that as the cement is added to the soil, the liquid limit drops to 51. With the addition of 10% sawdust to 5% cement with organic clay soil, the liquid limit increased by 7.10 % (i.e., from 83.1 to 89). Increasing the amount of sawdust to 15% and 20%, the value of the liquid limit was less and, respectively, 3.49% and 1.08%. The plastic limit has increased by 55.84% for the treated sample of 10% sawdust to 5% cement with organic clay soil from 45.45 to 70.83. With increasing the amount of sawdust to 15% and 20%, determining the value of the plastic limit was difficult. The plasticity index drops by 51.74% for the treated sample of 10% sawdust to 5% cement with organic clay soil from 37.65 to 18.17.

Silica content and mineralogy control the liquid and plastic limits of soil. The increase in liquid limit can be attributed to the hydration process and the pozzolanic reaction of cement and moisture in the soil that forms silica. In addition, the difference between plastic and liquid limits depends on Specific surface areas, water absorption, and interparticle forces. The plasticity index decreases at 5% cement with 10% sawdust, indicating an improved stabilized soil.

5.2 Shear Strength

5.2.1 Vane Shear Tests and Direct shear test

Figure (4) shows that the undrained shear strength obtained from the vane shear test increased with the increase in sawdust percentage. When the cement only is added to the soil, the undrained shear strength of the natural organic clay soil rises to 51.29. With the addition of 10% sawdust to 5% cement with organic clay soil, the undrained shear strength has increased by 33.63 % from 14.54 to 19.430, and increased the sawdust amount to 15% sawdust, the value of undrained shear strength increased by 61.90 % to 23.54.

With the addition of 20% sawdust to 5% cement with organic clay soil, the undrained shear strength has increased by 20 %. The maximum undrained shear strength is for the organic clay soil with 5% cement and 15% sawdust compared with the other percentage.

In addition, the effective shear strength parameters obtained from the direct shear test were increased with the increase in sawdust percentage. The effective cohesion of the soil increased to 8.89 KPa at 5% cement only. With the addition of 10%, 15%, and 20% sawdust to 5% cement with organic clay soil, the value of effective cohesion has increased to 17.59 kPa,33.85 kPa, and 11.44 kPa, respectively.

The highest effective internal friction is for the organic clay soil with 5% cement and 15% sawdust, showing an increase to 26°, while the lowest effective internal friction is for the organic clay soil with 5% cement and 20% sawdust showing a reduction to 23° in comparison to the other stabilized sample.

Cement was added to bind the sawdust and soil particles together. Thus, the reduction in shear strength resistance at a mixture of 5% cement with 20% sawdust can be due to excessive sawdust and cement not being able to bind the mixture.

The above results could conclude that the maximum shear strength is achieved at 5% cement and 15% sawdust, making it the optimum mixture. Also, sawdust works as a good filler and can improve the soil.

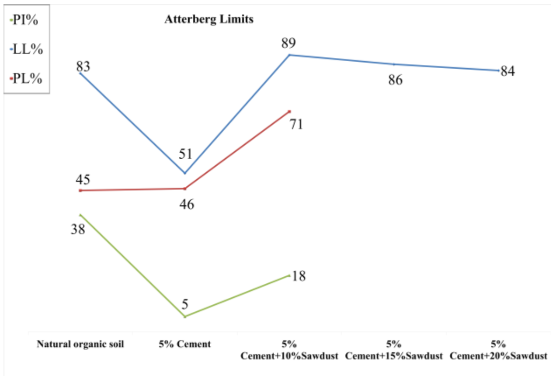

Figure 3: Atterberg limits of soil with sawdust percentage

5.3 Compressibility

5.3.1 Pre- consolidation pressure, σ'$_p$

Pre-consolidation pressure is the maximum past vertical adequate pressure applied on the soil sample. Pre-consolidation pressures (σ'$_p$) were determined using Semi log plots of (e-log σ'$_v$) using the Casagrande graphical method, as shown in Figure (5).

Results show that Pre-consolidation pressure (σ'$_p$) of the natural organic clay soil increased from 81 kPa to 97 kPa with the increase in sawdust percentage.

5.3.2 Void Ratio

The natural organic clay soil had a void ratio of 1.67. The void ratio (e) value had decreased by 15.29% from 1.70 to 1.44 at the mixture of 5% cement with 10% sawdust, while it increased by 18.24% from 1.70 to 2.01 at a mixture of 5% cement with 20% sawdust, as shown in Figure (6). The lowest void ratio is at 5% cement with 10% sawdust.

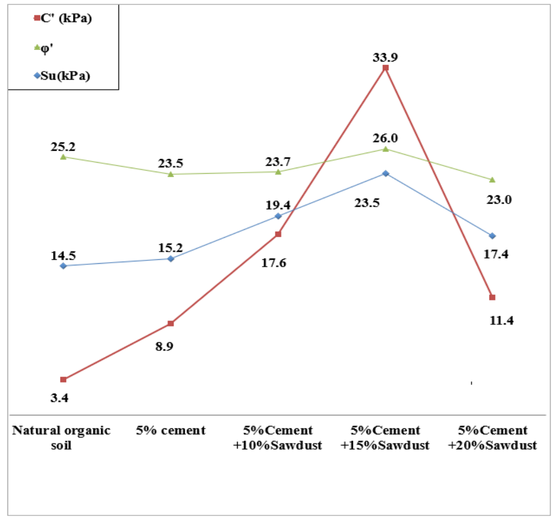

Figure 4: Variation of Shear Strength with Sawdust Content

5.3.3 Consolidation Parameters

Compression index (C_c) values had decreased by 18.64% at the mixture of 5% cement with 10% sawdust while increased to a maximum value of 13.56 % in a combination of 5% cement with 20% sawdust. The mix of 5% cement with 10% sawdust has the lowest compression index, and the value of C_c increases when more than 10% of sawdust is added to the cement-organic clay soil. This behavior could be because C_c depends mainly on the void ratio and a mixture of 5%cement with 10% sawdust had the lowest void ratio compared with the different percentages of sawdust.

Recompression Index (C_r) values were decreased to 0.19 at a mixture of 5% cement with 10% sawdust, while it increased to 0.31 at a mix of 5% cement with 20% sawdust. These values could be that; the compression ratio C_r value depends mainly on the compression index, C_c, and void ratio.

In addition, O' Loughlin [22], classified organic soils by the compression ratio as very slightly compressible with C_r = 0 – 0.05, slightly compressible with C_r = 0.05 – 0.10, moderately compressible with C_r = 0.10 – 0.20, and very compressible with C_r = >0.20.

Therefore, the reduction in C_r value from 0.24 to 0.19 makes the soil in the range of very compressible soil, indicating an improvement in the soil. The mixture of 5% cement with 10% sawdust presents the best mixture with the lowest compressibility.

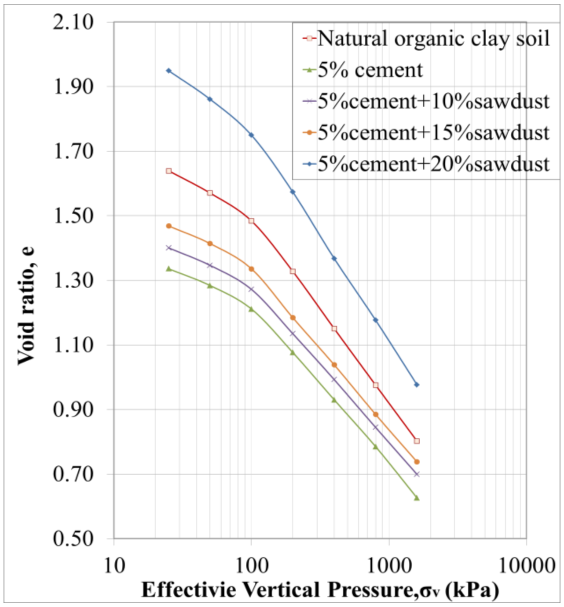

Figure 5: Compression (e-log σ'$_v$) curves

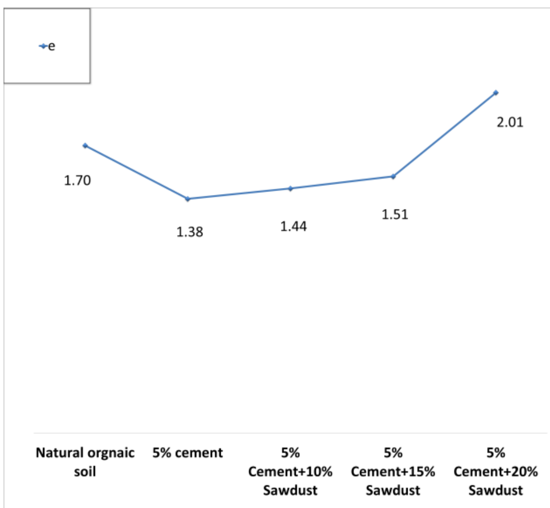

Figure 6: Variation of Void ratio with Sawdust Content

Swelling Index (C_s) values had decreased by 20.0% from 0.25 to 0.20 at a mixture of 5% cement with 10% sawdust, while it increased in all other mixtures until it reached the highest value of 0.30 at 5% cement with 20% sawdust. These values are because both cement and sawdust have water-absorbing characteristics. The lowest swelling index is at 5% cement with 10% sawdust. Figure (7) shows the variation of compression parameters with Sawdust Content.

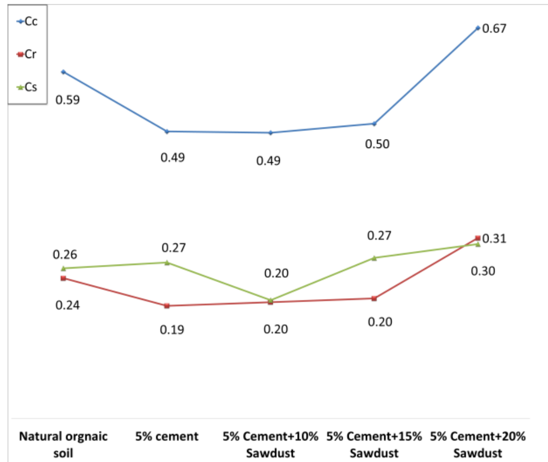

Figure 7: Variation of Compression parameters with Sawdust Content

5.3.4 Coefficient of Consolidation, C_v

The reduction rate of coefficient of consolidation, C_v, decreases as the pressure increases. Due to flattening time settlement curves, the determination coefficient of consolidation at initial pressure increments of 0-50 kPa was impossible. Thus, these values were calculated and plotted, as shown in Figure (8).

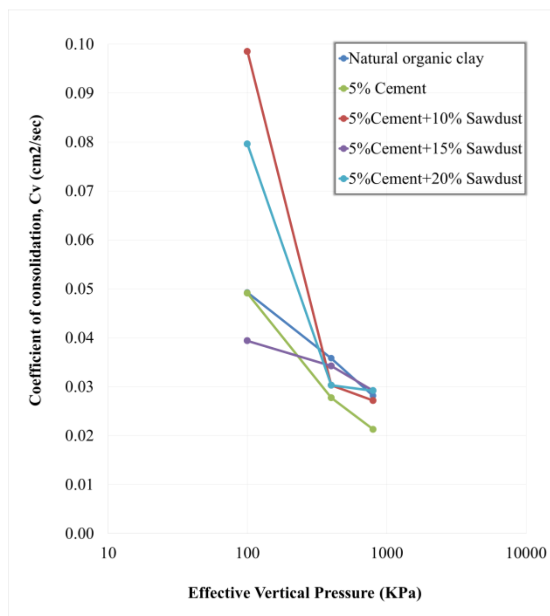

Figure 8: Coefficient of consolidation vs. effective vertical pressure

5.3.5 Coefficient of Compressibility, a_v

Coefficient of compressibility, a_v is the rate of change of void ratio, e with respect to the applied effective pressure, p during compression. The coefficient of compressibility depends mainly on the void ratio. Therefore, the lowest value of av was at 5% cement with 10% sawdust, and the highest value of av was at 5% cement with 20% sawdust, as shown in Figure (9).

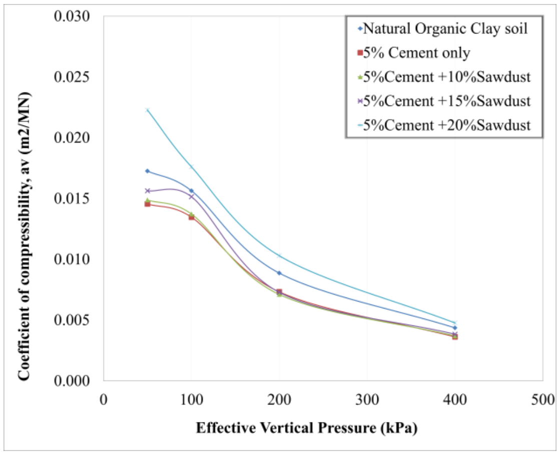

Figure 9: Coefficient of compressibility vs. effective vertical pressure

5.3.6 Coefficient of Volume Change, m_v

Coefficient of volume compressibility, m_v is the volume decrease of a unit volume of soil per unit increase of effective pressure during compression.

The coefficient of volume change depends on the void ratio. Therefore, the lowest value of m_v was at 5% cement with 10% sawdust because this mixture has the lowest void, while the mix of 5% cement with 20% sawdust has the highest mv because this mixture has the highest void ratio, as shown in Figure (10). The applied load compacts the tested sample, reducing its height and corresponding void ratio. Therefore, it could be concluded that the optimum mixture with the lowest settlement is 5% cement with 10% sawdust.

6. Comparison

Harnzani [8] has investigated the effect of using sawdust on shear strength properties of peat soil with 5% cement for zero curing day and after 28 curing days.

The results showed that at zero days of curing and 28 days of curing, the effective shear strength parameters, cohesion, and internal friction of peat soil have increased with sawdust to a maximum value at a mixture of 5% cement with 15% sawdust. Then they decreased at a mixture of 5% cement with 20% sawdust.

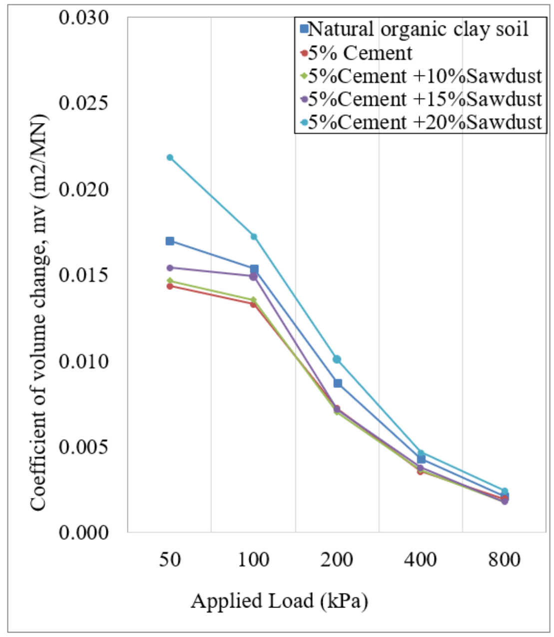

Figure 10: Coefficient of volume change variation .with sawdust percentage

The highly organic clay stabilization mixture with 5% cement and 15% sawdust had the highest effective cohesion value with the highest effective internal friction. While the stabilization mixture of 5% cement with 20% sawdust had the lowest effective cohesion value and the lowest effective internal friction, as shown in Figures (11) and (12), respectively.

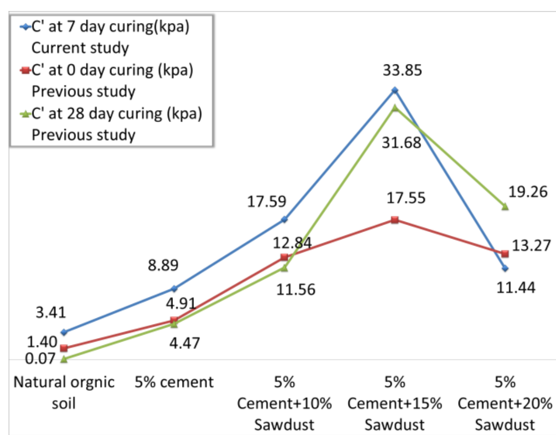

Figure 11: Variation of Effective Cohesion with Sawdust Percentage

Both studies showed the same behavior at different curing periods. Thus, it could conclude that the mixture of 5% cement and 15% sawdust is the best combination and is recommended to improve organic soils since it shows high values improvement.

The effective cohesion of stabilized highly organic clay is higher than that of stabilized peat soil in the previous study because highly organic clay soil has more mineral solid particles attributed to the secondary Pozzolanic reaction, causing increasing soil strength.

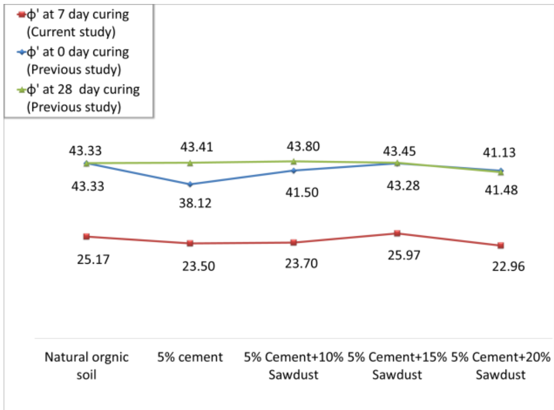

Figure 12: Variation of Effective Internal angle with Sawdust percentage

7. Conclusions

In the present study, organic clay soil was stabilized with cement as a binding agent and sawdust as an additive. The mixed samples were cured using a water-curing technique to simulate in situ conditions.
The binding agent, additive, and curing technique have been shown to increase the stabilized samples' shear and consolidation parameters values at the end of the 7-day curing period.
The best combinations of cement and sawdust that give higher shear results in both tests are 5% cement with 15% sawdust.
The best combination of cement and sawdust that gives lower consolidation results is 5% cement with 10% cement sawdust.
The use of sawdust reduces the requirement for cement and works as an excellent filler material to fill the voids between soil particles.
The technique of stabilization presented in this study can be applied in the field by mixing organic clay soil with cement and sawdust and compacting the site at the soil's natural moisture content.

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