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Laboratory Compaction Method of Soft Clay and Natural Plant Fiber/Shell Mixtures

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Abstract. One method of soil stabilization is to mix the soil with natural materials such as fibers or shells from plants. Generally, the samples are compacted in a laboratory by mean of Standard and Modified Proctor Compaction tests. The results of compaction are the relationship between water content and density, as indicated by the dry unit weight of the samples. In principle, this compaction process reduces the pore space filled with air in the soil. In this condition, soil is not saturated with water. The method cannot be used to compact soils that are in water-saturated conditions such as soft clay soils which are commonly found in wetland areas. This paper focuses on describing methods for compacting soft clay mixed with additional materials such as fibers and shells from plants. Two steps must be taken to compact samples of mixed soil and natural material. Firstly, determining the percentage of the mixture at which the sample can be compacted, and secondly, determining the optimum fiber/shell content to produce maximum density. The equipment and energy used are the same as the Proctor standard compaction test. Examples of calculations and results obtained for each material (i.e., empty fruit bunches and oil palm shells) are presented and discussed in the paper. Compaction procedures in the laboratory for the mixture of soft clay and other materials are also suggested in the paper.

1. Introduction

Soil compaction is a severe problem in modern agriculture, mainly in soils with high clay content due to heavy equipment [1]. Hydromorphic and/or anoxic conditions occur due to a reduction in air permeability and hydraulic conductivity of soil [2]. In addition, two plants whose species are very close have very contrasting responses in soil compaction [3]. With a combination of light and water factors, denser soil results in worse seedling growth [4]. Dense soils can also inhibit seedling growth in the early years and can even more severely reduce plant populations (cork oak) [5]. There are many more unfavorable effects due to soil compaction both in agricultural and forest lands. However, soil compaction is still required to improve infrastructure and access to the land.

In the field of civil engineering, soil compaction is carried out to increase bearing capacity and reduce soil compressibility. For special case, compaction is performed to minimize the coefficient of soil permeability. In the laboratory, compaction is carried out based on the standard Proctor compaction test (i.e, ASTM D698 [6], AASHTO T99 [7], SNI 03-1742-1989 [8]) and modified Proctor compaction test (i.e., ASTM D1557 [9], AASHTO T180 [10], and SNI-03-1743-1989 [11]). In principle, compaction is an attempt to reduce the volume of pores filled with air (unsaturated soil conditions) at different water contents. Two important parameters are obtained in the test, namely optimum moisture content and maximum density. This compaction also has a close correlation with further tests that require compaction data (i.e., California Bearing Ratio/CBR test) [12].

Although it has been standardized, this method is widely used in recent studies, especially concerning material and soil improvement. Stabilizing agents used include one or two inorganic materials such as lime [13], bentonite [14], lime and fly ash [15], and cement and palm kernel shell ash [16], or organic materials such as fiber [17]. The mixture of soil with a combination of organic and inorganic materials such as bottom ash and Areca fiber can also be used to increase soil shear strength [18]. However, all mixtures are compacted with standard or modified Proctor in unsaturated conditions.

Some researchers have conducted research to obtain compaction methods in the laboratory. In the late sixties, [19] suggested the vibrational method, which was considered to represent the conditions of compaction in the field. [20] developed a compaction tool with a smaller diameter mold (i.e., 76.2 mm) and allowed the diameter and weight of the rammer to be the same as the standard. In order to apply the same energy, the number of blows was reduced to 14 per layer. [21] proposed the static packing pressure method. The packing pressure applied was analogous to the same pressure as the Proctor standard. This method is considered to be faster, easier, and simpler to implement in a laboratory. Also, with the static compaction method, [22] found that a pressure of around 820 kN/m^2 produced the same compaction curve as that produced using the standard Proctor. [23] presented the gyratory method for compacting the soil. It was found that a standard Proctor can be achieved at 200 gyrations, 1.25 degrees of angle of gyration, and vertical pressure of 200 kPa. Again, these recommended methods are only for compacting unsaturated soils and cannot be used directly for soft saturated soils. Sometimes in the field, soft soil has a higher moisture content than the liquid limit.

This paper discusses the method of compaction of water-saturated soft clay by adding natural stabilizing agents (i.e., fiber of oil palm fruit bunches and oil palm Kernel shells) without drying the soil. Soft soils with different water content conditions (i.e., higher and around the liquid limit) were used in this study.

2. Materials and testing program

The materials used in this study were two soft clays from around Banjarmasin, oil palm Kernel shells, and natural fiber from oil palm empty fruit bunches. The properties of each material and procedures performed are described as follows:

2.1. Soft soils

Properties of soft soils used in this study are summarized in Tables 1 and 2. Both soft soils are equally classified as OH (i.e., organic soils with high plasticity). In addition, the two clays have almost the same liquid and plastic limits, which are 61% and 34.87% for Soil 1, and 57.85% and 35.01% for Soil 2, respectively. Furthermore, Soil 1 was used for research with fiber, while Soil 2 was for the shell.

The composition of the two samples is also almost the same, both fine and clay contents. Two significant properties that differ and affect the behavior of the clay are specific gravity and natural water content. The effect of natural moisture content will be discussed further in this study.

Properties		Soft soil
Specific gravity		2.31
Water content	%	106.07
Liquid limit	%	61.00
Plastic limit	%	34.87
Plasticity index	%	26.13
Fine content	%	95.12
Clay content	%	56.32
Soil type	USCS	OH

Table 1: Summary of Soil 1 characteristics used

Properties		Soft soil
Specific gravity		2.59
Water content	%	57.33
Liquid limit	%	57.85
Plastic limit	%	35.01
Plasticity index	%	22.84
Fine content	%	94.07
Clay content	%	56.10
Soil type	USCS	OH

Table 2: Summary of Soil 2 characteristics used

2.2. Fiber of Oil Palm Empty Fruit Bunches

The fiber used was empty fruit bunches (EFB) as a product of palm oil processing in PT. Perkebunan Nusantara XIII, Pleihari. The fiber has initial water content and a density of 9.8% and 0.45 g/cm^3, respectively. The fiber density is very close to those of natural fibers of coil and sisal (i.e., 0.67-1.07 g / cm3), as reported by [24]. The length of the fiber used was 10 cm. The fiber has a moisture content of 415.87% after being soaked for three days showing its ability to retain water is very high. The porous surface, as shown in Figure 1 (a), lets it absorb more water than its weight. The properties of the fibers used are summarized in Table 3.

Properties		EFB fiber
Water content	%	9.8
Density	g/cm^3	0.45
Water absorption:		
one day	%	384.99
two days	%	422.71
three days	%	415.87

Table 3: Summary of fiber from empty fruit bunches (EFB) characteristics used

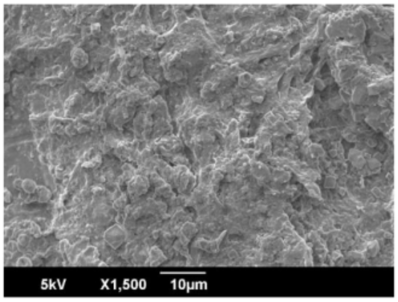
2.3. Palm Kernel Shell

The Palm kernel shell used was taken from PT. Agri Bumi Sentosa (ABS). The sample has a moisture content of 51.84%, a volumetric weight of 0.465 g / cm3, and the ability to absorb water 3-6%. Different from the porous fiber surface, the shell surface appears denser and does not have too many pores (Figure 1 (b)). This material has a specific gravity between 1.14-1.37 [25]. The sample size is uniform at 4.76 mm (sieve No. 4) to accommodate the size of the sample and the mold used.

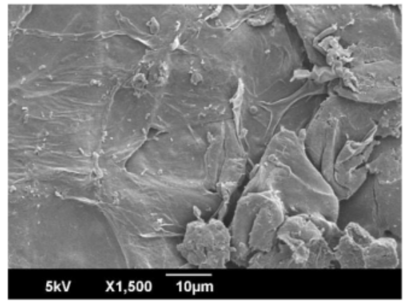
2.4. Research procedures:

Trial and error were carried out to get the right percentage so that soft soil can be compacted. The percentages obtained for fiber and shell were 5% and 2.5%, respectively. This method takes too long and requires a large amount of sample. The soil and fiber mixtures were prepared with the addition of 1% fiber content (i.e., 5%, 6%, 7%, and 8%) on the dry weight basis. Different from fiber, the percentage of shell addition was done every 5% because, in the trial error, no maximum density was found until the addition of 10% of the shell.

Samples were stored in a closed place and allowed to stand for one day. Compaction was carried out using the same tools and procedures as the Standard Proctor for each sample. Fiber content and dry unit weight data were plotted to obtain optimum fiber content and maximum dry density. The same procedure was carried out on a mixture of soil and shells.



(a)



(b)

Figure 1: SEM photos of the surface of the material used (a) fiber, and (b) shell

3. Results and Discussion

Based on its consistency, clay can be formed or squeezed when the soil is plastic. Soil starts to become plastic when its water level is between the liquid limit and the plastic limit. The followings are the results of compaction of a mixture of soft soil with oil palm empty fruit bunches and oil palm Kernel shells.

3.1. A mixture of soft clay and oil palm empty fruit bunches

After performing trial and error mixtures, it was found that the sample can be kneaded and formed at 5% fiber content. Thus, the percentages of fiber content prepared were 5, 6, 7, and 8%. Compaction was carried out in three layers, with a number of blows of 25 per layer. Figure 1 shows the results of the compaction of soft clay mixtures at different fiber contents. The soil density is indicated by dry unit weight [6], [7], [8]. Two important parameters were obtained from the graph, namely maximum density ($\gamma_{d\ max}$) and the optimum fiber content of 0.92 g/cm^3 and 7%, respectively. As shown in the figure, dry density increases with increasing fiber content up to 7%, followed by decreasing the dry density afterward. This behavior can be explained by the sample's appearance shown in Figure 2 [26]. The sample with a fiber content of 5% to 7% shown in Figure 3 (a) - 3(c) seems dense, with small pores. The difference appears in the sample with a fiber content of 8% (Figure 3 (d)).

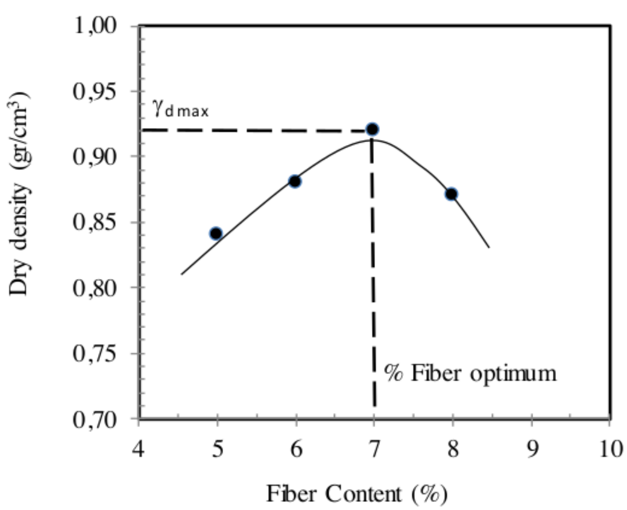


Figure 2: Dry density as a function of fiber content

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High fiber content results in the formation of large pores in the sample. In addition, sample was difficult to compact. The increase in density of the entire sample is due to the presence of fiber in the sample and high ability of the fiber to absorb water. At lower water content, the soil was easily to compact due to behaves plastically. The water content of the samples after compaction test was 62.40%, 56.98%, 51.05%, and 51.51% for samples with a percentage of fiber 5%, 6%, 7%, and 8%, respectively. All samples have water content less than the liquid limit.

Figure 3: Photos of soft soil at difference fiber content (a) 5, (b) 6%, (c) 7%, dan (d) 8% [26]

[27] uses the liquid limit and plastic limit parameters in determining the percentage of water mixtures of soil mixed. More details, [28] and [29] found empirically that the optimum moisture content and maximum density are functions of the plastic limit. Both (i.e., liquid limit and plastic limit) cannot be applied directly to this sample due to interactions between soil and fiber. However, changes in soil behavior from being liquid to plastic are important finding in this study.

3.2. A mixture of soft clay and palm oil Kernel shell

Although the properties are almost the same between Soil 1 and 2, the initial water content of soft soil mixed with the Kernel shell of palm oil is almost the same as the liquid limit (Table 2). Based on experiments, the soft clay can be compacted at a shell content of 2.5%. So, the compaction was performed at shell contents of 2.5%, 5%, 10%, 15%, 20%, and 25%. Figure 4 shows the compaction curve as a function of shell content. From the picture, the density decreases with increasing shell percentage. The behavior shows that the function of the shell in the mixture is more as a filler. However, the presence of a shell in the mixture allows soft clay to be compacted using the dynamic method (i.e., standard Proctor). The appearance of compacted samples is shown in Figure 5.

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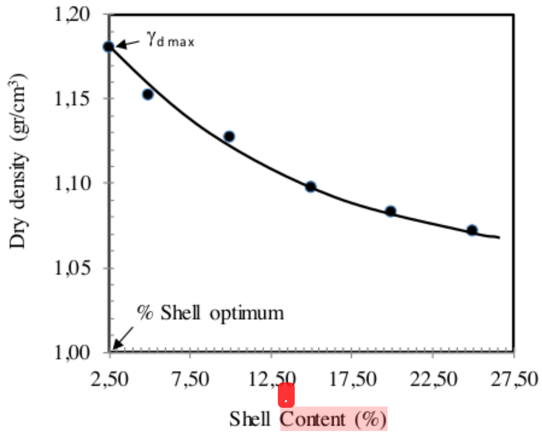
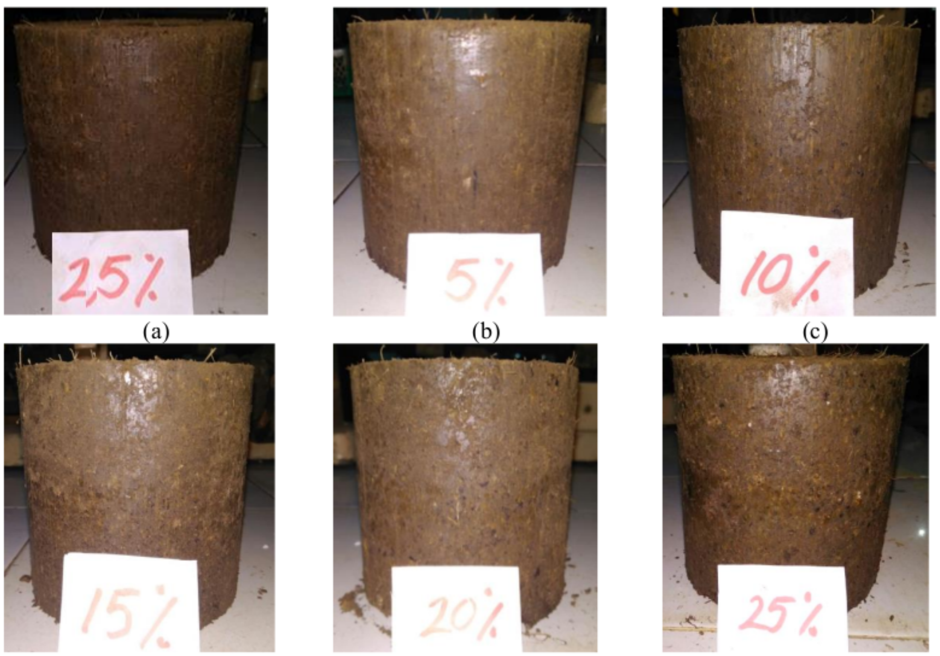


Figure 4: Dry density as a function of shell content



(a) (b) (c)
(d) (e) (f)

Figure 5: Photographs of soft soil and shell mixtures at different shell contents (a) 2.5%, (b) 5%, (c) 10%, (d) 15%, (e) 20%, and (f) 25%

3.3. Proposed laboratory compaction method

The compaction procedures that is proposed based on previous investigation are as follows:

1. Soil that is maintained, its water content is prepared with a minimum weight of 100 g.
2. Fiber or other material of reasonable size (for example, the fiber length of approximately 1 cm) mixed with soil with a percentage of 1, 2, 3, 4, and 5% on the dry weight basis.

3. Samples are stored in a closed place and allowed to stand for approximately one day. Curing time can be longer when considering the time function.
4. The mixture is kneaded gently. The specimen that can be formed, such as the plastic limit test (ASTM D4318) [30], is a sample that can be compacted. This mixture percentage is used as the first percentage of the mixture.
5. For compaction tests, four to five soft soil samples are prepared to weigh at least 2500 g per sample.
6. Fiber with an appropriate weight so that the percentage obtained in step 4 can be reached. Add fiber by adding a percentage of at least 1% to the next sample. The mixture is then allowed to stand for one day in a closed place.
7. Compaction is carried out using the same tools and procedures as the Standard Proctor for each sample.
8. Fiber content and dry unit weight data are plotted to obtain optimum fiber content and maximum dry density.

4. Conclusions

Research on compaction of soft clay soils mixed with natural stabilizing agents has been presented. Methods to conduct compaction test have also been presented. The circumstances that can be concluded are as follows:

1. Optimum fiber content to reach the maximum density of soft soil and fiber mixture is 7%. It is not found in a mixture of soil and shells.
2. The relationship between dry unit weight and the percentage of material depends on the function of the material in the mixture. When there is an interaction between the material with the soil so that the soil properties are better, the optimum percentage can be determined.
3. Additional materials can also function as fillers that allow soft soil to be compacted; this was found in the shell used in this study.
4. The ability of the stabilizing agent to absorb water also affects the compaction process.

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