Performance of Coir Fiber Addition for Clay as a Sub-Grade for Pavement Design

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Abstract. Clay soil behavior often becomes problematic with building construction, it is about the shrink-swell behavior in clay when influenced by water content. Coconut husk fiber (coir fiber), in general, is an industrial waste which is still infrequent to be re-used. This study aims are to determine the effect of coir fiber addition for mechanical stabilization of clay soil in terms of CBR (California Bearing Ratio) value. Soil samples used for laboratory tests were collected from Ulee Glee area of Pidie Jaya Regency. According to AASHTO classification, the soil category is A-7-5 (25) while for USCS classification, the soil is OH (Organic High). The percentage of added coir fiber was 0%, 0.2%, 0.4% and 0.6% of the dry weight of the soil with a coir fiber length of 2 and 3 cm. Two treatments of clay-coir fiber mixing method were applied namely direct mixing and mixing by layers. The results of natural soil compaction test obtained that OMC (Optimum Moisture Content) value and dry soil weight ($\gamma_d$max) was 26.8% and 1.34 gr/cm^3 respectively. The highest CBR results were obtained for clay soil with 0.4% coir fiber 3 cm (direct mix) with CBR value = 17.7%. Furthermore, the lowest CBR value is 10% for percentage of 0.2% with coir fiber length 2 cm (by layer). In general, high organic clay soil with coir fiber mixture addition is able to increase the CBR values if compared to CBR of natural soil which is 8.15%. Thus, the use of coir fiber in this study is able to improve soil bearing capacity which is useful for construction material in the site.

1. Introduction

In civil engineering works, the ground must have sufficient bearing capacity both as a ground construction and as a construction material. As a construction material, generally, the soil used as embankment material is taken from the borrow area, which is generally in the form of cohesive soil such as clay. The problem of soil characteristics for construction may because of environmental conditions. Tropical season of dry and wet seasons give a great influence on soil behavior. Especially if dealing with expansive clay soil. Clay has properties that are very sensitive to the influence of water content and have high shrink-swell behavior properties.

Several latest researches to improve the soil strength by addition of chemicals and fiber materials have been done so far. [1] studied the effect of palm oil clinker concrete pile with foamed concrete pile as a soft soil floating foundation. The used of lime-clay stabilization for mechanical properties improvement of expansive soil was conducted by [2]. [3] studied the shear strength of soft clay with the reinforcement by encased lime bottom ash column. The result shows that soft clay shear strength improves by the installation of a single column of encapsulated lime bottom ash.

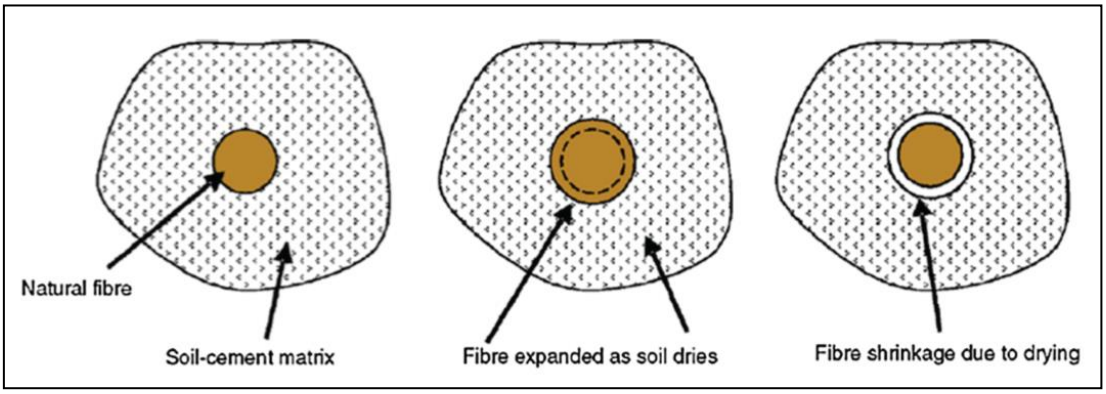

Figure 1. Influence of water absorption on natural fiber

Natural fiber used for soil improvement were already implemented by several previous research. Bagasse fiber mixed with hydrated lime was studied by [4] for expansive soil treatment. The result obtained that compressive strength of expansive soil increase by the increment of fiber-lime to the soil. Moreover, [5] found the improvement of clay soil geotechnical properties mixed with cement-rubber fiber which containing 6% of cement and up to 7.5% rubber fiber that can be used as civil engineering work material. [6] studied the effect of lime-rice husk ash and waste plastic fiber for engineering properties of silty soil. They found that the mixture ranges from 0.4-08% of dry mass were able to increase the value of compressive, tensile, and shear strength of silty soil properties.

Table 1. Coir Fiber Characteristics [11]

Characteristics of granulated	Results
Average length of the granulated one	10-20mm
Average thickness	0.1mm
Amount (percentile in weight)	0.5-0.7%
Ph	5.4
Electric Conductivity	1.8dS/m
Capacity of cationic exchange	92
Relation C/N	132
Specific mass	70g/L
Water retention	538ml/L
Capacity of aeration	45.5%
Porosity	95.6%

Coconut based stabilization agents were already applied for civil engineering material construction stabilization. The powder of coconut shell was used by [7] for modified asphalt binder. Further previous researches about coir fiber influence to soil were experimented by [8]-[10]. The research of [8] uses a nano-modification of coir fiber for treated with lime-marine clay in terms of shear strength parameter. The result shows good reaction between coir fiber and lime-marine clay for the value of shear strength, durability and also increase the tensile strength of the soil. Moreover, cracking of soil can also be prevented by using coir fiber as reinforcement according to [9], it was because of multifilament natural content and high lining content of the fiber.

A research article of [10] investigated comprehensive research for improvement of compressibility, swelling and strength parameter for black cotton soil with coir fiber stabilization. Furthermore, [11] conducted review research of coconut shell and fiber utilization for road construction. Their research result showed that coconut shell and fiber were able to improve the asphalt mixture of engineering properties when mixed with modified bitumen.

(a) (b)

Figure 2. Clay-Coir Fiber Samples for CBR Test, (a) top view of soil specimen for CBR test (b) soil specimen with coir fiber mixing stabilization

According to [12], there are two types of fibers used for soil improvement namely natural and synthetic fibers. Coir fiber, sisal, pal fiber, jute, flax, barely straw, bamboo, and cane are the example of natural fibers. Furthermore, polypropylene, polyester, polyethylene, glass, nylon, and steel fibers can be classified as synthetic fibers. Coir fiber, as a natural fiber is also one of the industrial wastes has also being considered as one of the clay mixtures to increase the bearing capacity and strength of the clay. Coir fiber is a fibrous material of matured coconut that has a thickness of about 3.5-5 cm with moisture content approximately 0.8-3.2% [13] and is the outermost part of the coconut fruit. Coir fiber is containing cellulose, lignin, pectin, tannin, and other water-soluble substance [12]. Coir composition is 43% of cellulose, 46% of lignin, 0.25% hemicellulose [13]. Good coir fiber basically has properties that are durable, friction-strength, not easily broken, resistant to water and also resistant to fungi or pests. Long-lasting coir fiber service life is around 4-10 years [12]. In one coconut can be obtained an average of 0.4 kg of coir where the coconut fiber contains almost 30% fiber. The properties and characteristics of coir fiber were shown in [11] as can be seen in Table 1. The influence of natural fiber for stabilization of soil can be imagined as in Figure 1. The absorption of water by natural fibers has a vital outcome on their adhesion [13]. In general, from previous studies, coconut fiber was able to increase soil strength but not significantly. With the right mixing method and good quality of coconut fiber, it is expected to maximize the use of coconut fiber in stabilizing clay.

Clay used in this study was collected from Ulee Glee Pidie Jaya area. Reasons for taking soil samples in Ulee Glee is because the soil was used for embankment construction of buildings and roads in Pidie Jaya Regency and its surroundings. Visually, this type of cohesive soil is basically not good for use in road embankments or buildings because in general cohesive soils have high shrink-swell behavior and low bearing capacity. The previous study regarding soil characteristic in Pidie Jaya area was also conducted and presented in several up to date researches. [14] evaluated the uplift force value of red clay soil in Pidie Jaya. The result of optimum moisture content of Pidie Jaya clay uplift force and swelling pressure was 2.466 kg and 0.868 cm respectively. Furthermore, [15] learned about expansive soil used as road sub-grade in Pidie Jaya. The article obtained that untreated clay soil of Blang Dalam – Pidie Jaya free swelling is 1.141% with swelling pressure for 23.18 kN/m^3.

The location of Pidie Jaya Regency which is an earthquake-prone area requires the use of good quality construction materials so that it can reduce the possibility of construction failure and achieve the

construction age in accordance with the plan. Previous earthquake disaster in Pidie Jaya on December 2016 has caused about 104 human loss, more than 2,474 building need to be reconstructed, approximately 10 km roads and 50 bridges destroyed [16]. Pidie Jaya located along and close to Sumatera crust and some local faults like Lhokseumawe and Samalanga-Sipopok faults or known as (SAM-SIP) faults [17]. Better plan to prevent accident and destruction are important in earthquake disaster zone construction as [18] conducted a risk analysis research in Aceh Province.

2. Material and Methodology

The soil used in this study is a classification of A-7-5 (25), which is clay with high plasticity according to the classification of AASHTO, and OH (Organic High), namely organic clay with medium to high plasticity according to USCS classification with a specific gravity (SG) 2.63. Visually this clay soil is a red color, has a sticky character when squashed by hand. Though, for dry water conditions, the soil feels very stiff and hard while in the wet condition the soil is weak and expanded.

From laboratory test results for physical properties of the soil, the liquid limit (LL) and plastic limit (PL) of the soil were obtained at 54.15% and 33.73% respectively. Grain size distribution of # 200 pass filter analysis test obtained at 96.78%. All the physical parameter and mechanical parameter obtained were based on laboratory experiment of American Society of Testing and Materials (ASTM) standard.

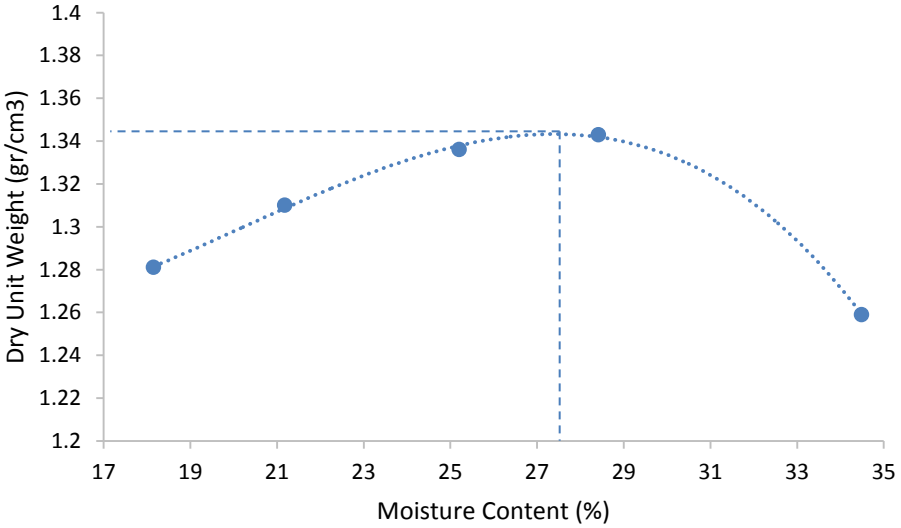

Figure 3. CBR result of high organic clay soil – coir fiber stabilization

Standard Proctor tests were performed to determine the optimum water content (OMC) value as in Figure 3. Total of 39 soil samples was prepared for CBR testing as can be seen in Table 2. Two lengths of coir fiber were arranged manually namely 2 cm and 3 cm. Coir fiber was dried under room temperature for 3 days. Manual sort and cut were conducted to obtain required length of coir fiber. The percentage between the mixture of soil and coir fiber was determined for 4 conditions, namely 0%, 0.2%, 0.4%, and 0.6%. The selected percentage was based on some previous study such as from [19] as they use 0%, 0.5%, 1.0%, and 1.5% of coir fiber in soil treated. The specimens were made using CBR molds by compaction method (ASTM D 1883-73) with a soil weight per test object approximately 4500 grams. Compaction test results (proctor standard) obtained the maximum dry unit weight (γ_{dmax}) 1.345 gr / cm^3 with optimum water content (OMC) was 27.5 % as can be seen in Figure 3. The stabilization mixing treatment used were direct mixing between soil and coir fiber and by mixing with layers of fiber in one sample specimen. The direct mixing treatment is mixing the clay with coir fiber before compaction. This treatment method was very common in soil stabilization techniques. On the other hand, layers treatment is coir fiber was added during soil specimen preparation of compaction test. The coir fiber was added after each layer of compaction test. This treatment method was trying to adopt simple site work method in soil compacting while contractor

pours the stabilization agent with specific amount after every layer compacted and continue compacting next layer with similar action. This treatment is suited for existing road construction techniques. The purpose of the difference in treatment of this soil-coir fiber mixture is to see the effect of the mixing treatment method on CBR values. List of test specimen designs and sample results of test objects can be seen in Table 2 and Figure 2.

Table 2. Soil Sample Designs for CBR test

Fiber Length	Mix Percentage (%)	Stabilization Method		Total
		Direct Mix	Layers	
2 cm	0	-	-	3
	0.2	3	3	6
	0.4	3	3	6
	0.6	3	3	6
3 cm	0.2	3	3	6
	0.4	3	3	6
	0.6	3	3	6
Total Sample				39

3. California Bearing Ratio Result

Detail of the CBR test result presented in Figure 4. The results showed that the addition of mixture variations in coir fiber percentage to Ulee Glee Pidie Jaya high organic clay soil affected the CBR value. The mixture between clay and coir fiber can generally increase the CBR value of high organic clay soil compared to the CBR value of natural clay soil sample (0% mix). The CBR value of natural soil without any addition is 8.15%, while all types of coir fiber mixtures with organic clay increase CBR values better than natural soil as shown in Figure 4. The highest CBR value of 17.70% was obtained from coir fiber 3 cm length with direct mixing treatment, followed by coir fiber 3 cm of layered treatment (16.15%). Additionally, the lowest CBR value was obtained in coir fiber 2 cm length with direct mixing treatment for 11.78% and layer treatment of 2 cm coir fiber length which is 10%.

The CBR testing results of 2 cm length coir fiber direct mixed treatment with a mixed variation of 0% obtained a CBR value of 8.15%. The most effective mixture was obtained at 0.4% addition of coir fiber, which is an increase in CBR value of natural soil by 93.62%. Whereas for the layer treatment mixing method for 2 cm length, the best CBR value was also for 0.4% mixture with an increase up to 66.38% from natural organic clay soil. Furthermore, the most effective percentage of coir fiber length 3 cm direct mixture treatment for CBR was obtained in 0.4% mixture for either direct mixed or layered treatment methods. The highest CBR value was 17.70% in the percentage of coir fiber 3 cm (mixed) 0.4% with an increase in CBR value more than double of natural CBR value of the soil that was 117.18%. Interestingly, the CBR value were decrease for 0.6% addition of coir fiber even still above CBR natural soil. It may because the quantity of coir fiber already too much compare to soil weight. The increment percentage of CBR value compared to natural high organic soil is presented in Table 3.

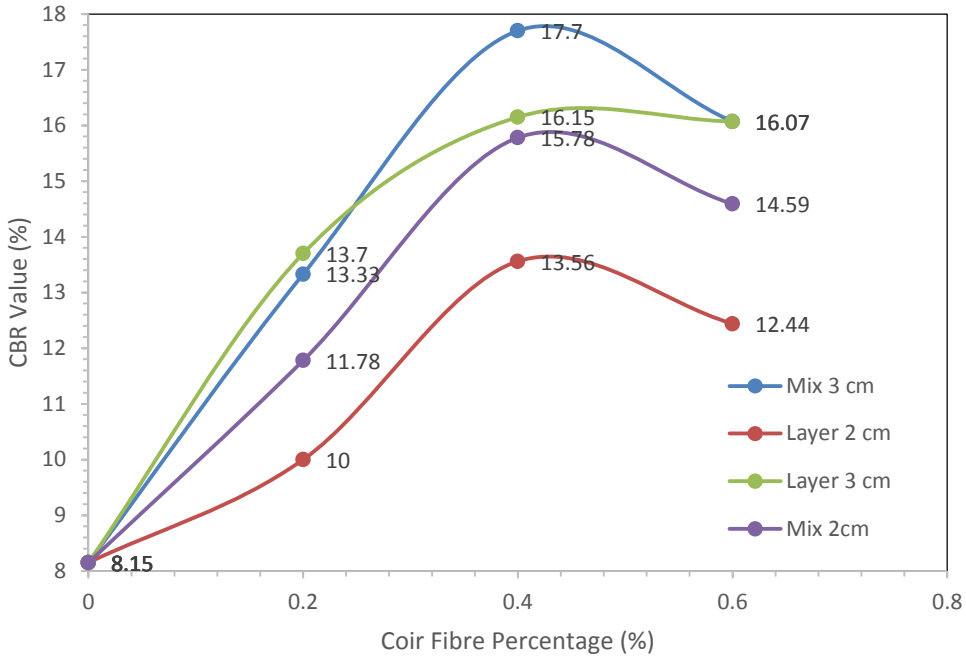

Figure 4. CBR result of high organic clay soil – coir fiber stabilization

Table 3. Coir fiber – clay soil CBR increment percentage from natural soil

Mix Percentage	2 cm (mix)		2 cm (layer)		3 cm (mix)		3 cm (layer)	
	CBR (%)	Increment Percentage from natural soil	CBR (%)	Increment Percentage from natural soil	CBR (%)	Increment Percentage from natural soil	CBR (%)	Increment Percentage from natural soil
0	8.15		8.15		8.15		8.15	
		44.55		22.70		63.56		68.10
0.2	11.78		10.00		13.33		13.70	
		93.62		66.38		117.18		98.16
0.4	15.78		13.56		17.70		16.15	
		79.02		52.64		97.18		95.46
0.6	14.59		12.44		16.07		15.93	

4. Conclusion

Based on finding results as explained previous, there are some highlights that can be considered for conclusions as follow:

- Clay which was stabilized with coir fiber by mixed treatment has higher CBR values compared to coir fiber with layered treatment.
- Clay-coir fiber with a length of 3 cm has higher CBR value compare to coir fiber with a length of 2 cm.
- The direct mixing treatment CBR results produce a higher value than the layered treatment method.
- However, the direct mixing method need more effort from contractors during application in the site if compared with layered treatment

5. References

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