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Key words: *generalized Zhurkov equation, errors, durability prediction, thermal fluctuation concept, economic efficiency*

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PHYSICAL AND ENGINEERING PROPERTIES OF PEAT SOIL STABILIZED WITH THE ADMIXTURE OF CaCO_3 +RICE HUSK ASH DUE TO WATER INFILTRATION FROM SURROUNDING AREAS

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Peat is a type of soil with high organic content, very low bearing capacity, and high uneven settlement. Some methods to improve soil have been applied to peat in order to make it strong enough for civilization-building foundation situated on it. Peat stabilization is a method that is continuously developed considering that the cost it needs is lower and this approach is more environmentally friendly compared to other methods. The admixture of lime (CaCO_3) and Rice husk ash, a new ecofriendly stabilizer material, has been applied to peat soil and showed a good result. However, in studies conducted previously, the effect of water infiltration from surrounding areas of soil was stabilized was not involved as variable influencing the change of parameter. Based on that, this laboratory study was carried out to model the real condition in the field when the stabilization is performed and to identify the physical and engineering changes of peat soil in the 10th, 20th, and 30th days of stabilization in its border and middle parts, with the percentage of material stabilizer 5%, 10%, 15% and 20% of the unit weight of the initial condition of peat. The result of laboratory test shows that the addition of admixture of lime (CaCO_3) and rice husk ash can improve the physical and engineering properties of peat soil are stabilized. Water infiltration occurred on peat soil is stabilized has not affected the physical and engineering properties of the soil. It can be seen from the physical and engineering properties of the border and central parts of peat soil is stabilized that still have a similar value. It is assumed to be caused by CaSiO_3 gel formed still needs a longer duration to become stable gel. However, in this initial study it was known that the more stabilizers added, made the better the parameters of the stabilized peat soil.

Key words: stabilization, peat soil, lime, rice husk ash, water infiltration

INTRODUCTION

Peat is the organic soil formed from soil decomposition within around 18.000 years [1]) with bad characteristics for civil building foundation. It is because of the low quality of physical and engineering characteristics it has. The physical characteristics of this soil include the ratio of organic content (Oc) >75%, unit weight (γ_t) around 1,0 gr/cm³, water content (WC) >500%, specific gravity (Gs) 1,2-1,6 and void ratio (e) 5-11. Due to those physical properties, peat soil has the very low bearing capacity (5-7, kPa) and the compression is big and uneven for a long period of time [2, 3, 4, 5, 6, 7, 8, 9] Some efforts for improving peat soil have been carried out to enable it to be a foundation of civil construction including the use of corduroy, wood mini pile, preloading, replacement, and stabilization. Yet, those methods (except the stabilization) need much cost and are not friendly for the environment [2, 7, 10] therefore stabilization methods of peat soil are continuously developed. One of the materials for stabilization is generally used is rice husk ash (RHA), as

it has a high rate of silica content [10, 11, 12], and it is an eco-friendly product from brick industry. Unfortunately, the use of RHA as stabilization material for peat soil has not considered the effect of water infiltration from surrounding areas while the peat that must be stabilized not in the whole part. Based on the description above, this study was carried out to identify the changes of peat soil parameters that are stabilized with RHA is mixed with lime (CaCO_3) due to water infiltration from the surrounding area and to identify the optimum percentage of RHA must be added for achieving better physical and engineering characteristics

INITIAL CONDITIONS OF PEAT AND STABILIZATION MATERIAL

Peat soil samples were taken from Bareng Bengkel village, Palangkarya, Central Kalimantan. Those samples had two different types: disturbed and undisturbed samples (Fig. 1). The disturbed sample was used to identify the physical and engineering characteristics of initial peat, while the undisturbed sample was occupied to

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model the peat stabilization that would be treated with RHA. Based on the test carried out on the undisturbed peat soil sample in the laboratory (Table 1) we found that the peat in Palangkaraya can be classified as Moderate Fibrous Peat Soil, Hemic, and Low Ash with high acidity, based on the ASTM D-4427-92 [13]. Besides that, the result of laboratory tests showed that peat soil in Palangkaraya was being studied was still under the investigation of other researchers [2, 5, 9, 13, 14, 15, 16, 17]. The microstructure of fibrous peat soil is quite different compared to other soil in general. Test conducted on initial peat soil using SEM (Scanning Electron Microscope) (Fig. 2) showed that fibrous peat has two different types of pores namely macropore (pores among fibers) and micropores (pores inside fibers). Because of those distinctive pore structures, peat soil has different behavior from clay [6, 100, 18, 19]. The curve of consolidation of fibrous peat soil consists of 4 components including immediate compression (si), primary compression (sp), secondary compression (ss) and tertiary compression (t) as presented in Fig. 3. For fibrous peat soil, the secondary compression is dominant.

Table 1: Parameter of initial peat soil

Soil Parameters	Unit	Peat Soil is researched	Findings of other studies
Specific Gravity (Gs)	-	1.51	1.4 - 1.7
Void ratio (e)	-	7.5	6.89 - 11.09
Unit Weighth ($\gamma(t)$)	t/m ³	0.981	0.9 - 1.25
Water Content (Wc)	%	511	450 - 1500
Organic Content (Oc)	%	98	62.5 - 98
Ash Content (Ac)	%	2	2 - 37.5
Fiber Content (Fc)	%	50.92	39.5 - 61.3



(a)



(b)

Figure 1: The process of taking peat soil samples; (a) disturbed sample; (b) undisturbed sample

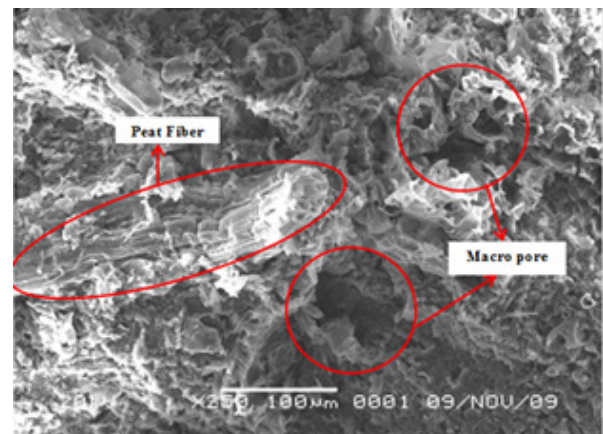


Figure 2: SEM of initial peat (Yulianto and Mochtar, NE., 2012)

The distinctive microstructure has also caused its compression behavior different from clay [3, 5] (Fig. 3).

The admixture of RHA and CaCO_3 is effective for peat soil stabilization because it does not contain silica. Through this addition, the soil will form water-insoluble gel [10]. Silicate calcium (CaSiO_3) gel is formed fills the space of peat pores and covers the fibers so that the physical characteristic of fibrous peat soil is stabilized will be better than the condition before the treatment. The result of the laboratory test of stabilization material showed that the highest amount of chemical composition of rice husk ash was the SiO_2 compound (75,88%) while that of the lime was CaCO_3 was 80.74% (Table 2 and Table 3).

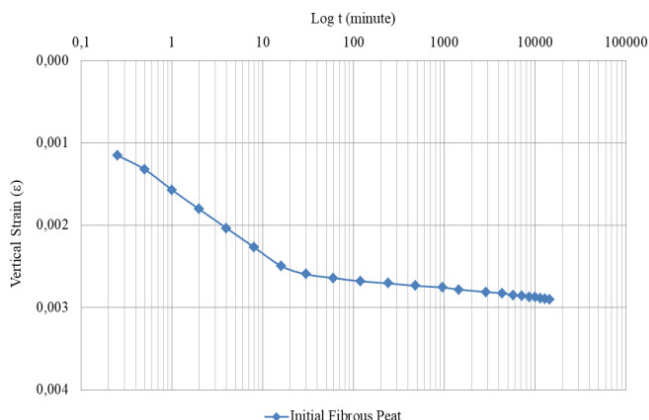


Figure 3: Curve of fibrous peat soil consolidation
One step loading ($\Delta \sigma = 50 \text{ kPa}$)

Table 2: Chemical Composition of Rice husk ash

Parameters	Result (%)
SiO_2	75.88
CaO	12.91
Fe_2O_3	0.21
SO_3	1.41

Table 3: Chemical Composition of CaCO_3

Parameters	Result (%)
Ca	27.64
CaCO_3	80.74
CaSO_4	38.78
$(\text{NH}_4)_2\text{SO}_4$	1.33
$(\text{NH}_4)_2\text{SO}_3$	0

RESEARCH METHOD

This study is laboratory-scale research by imitating the real condition of the field with a scale of 1:100. Peat soil was stabilized was put between other peats that were not stabilized (Fig. 4). The modeling box was made of airtight material (Fig. 5). The water content (WC) of peat soil was not stabilized maintained between 500% and 550% (based on the pre-condition / real condition of the field). The thickness of peat soil stabilized was 30 cm. To separate the peat soil stabilized from the one, we used wire mesh. This wire mesh is used to facilitate modeling in the model box when the stabilization stage is carried out because peat is very soft soil and to avoid the stabilized peat mixed with the initial condition peat but water filtration from the initial peat to stabilized peat still occurs the same as conditions in the field. The admixture was added into

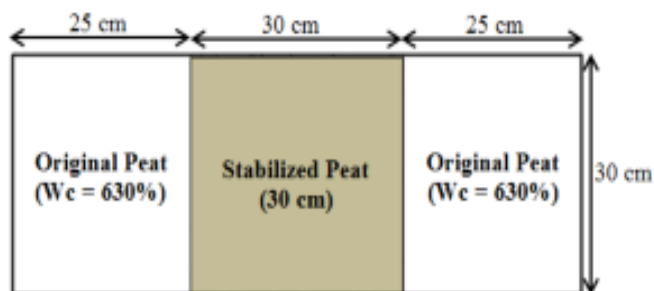


Figure 4: Top view of the physical model of fibrous peat soil stabilized in the laboratory.

the fibrous peat soil consisted of lime and rice husk ash based on the previous study [7] with the percentages of 5%, 10%, 15% and 20% from the γ_t value of initial peat soil. The test of physical characteristics of peat soil was stabilized was conducted in the central and border parts based on the Peat Testing Manual ASTM-1984 [20] in the curing periods of 10 days, 20 days and 30 days.

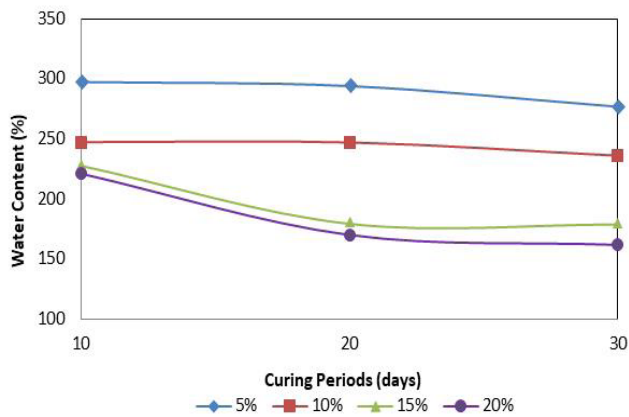


Figure 5: Box of stabilization model of fibrous peat soil

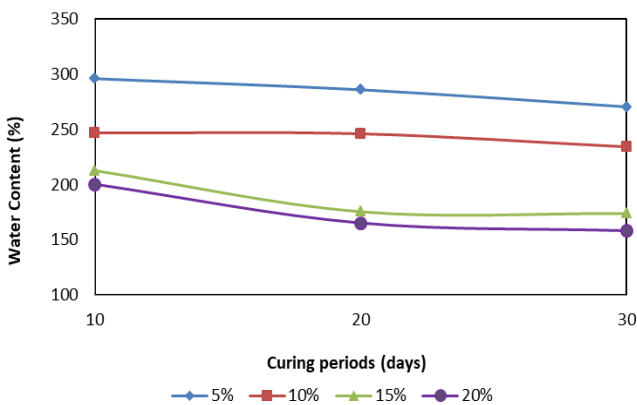
PHYSICAL CHARACTERISTICS OF PEAT SOIL STABILIZED.

The test on physical characteristics of stabilized peat conducted in the laboratory included the water content (Wc), Unit Weight (γ_t), Specific Gravity (Gs), Void ratio (e) and Organic Content (Oc). Fig. 6 shows the change of water content (WC) of peat soil stabilized with admixture of CaCO_3 and rice husk ash. There was a dramatic decrease in the water content of the peat soil as it was 500% in the initial condition to be maximum at 300% after the treatment. This was caused by the water in the peat soil macropores reacted with the stabilizer and formed silicate calcium (CaSiO_2) gel, while water infiltration happened on initial peat soil from surrounding areas was not as quick as in the pre-condition (before being filtered) as the pores of peat soil filled with stabilization material [7, 8, 10, 21]. The higher the percentage of the stabilizer added into the peat soil, the more water

content reduced. This condition should be considered to be normal considering that the more amount of stabilizer added, the higher the rate of water needed to react to form silicate gel. Besides that, one of the characteristics of rice husk ash is that it has high permeability [10]. Fig. 6 also shows a significant change in water content with the percentage of stabilizer from 5% to 15%, while in the use of stabilizer 20%, the water content change was almost similar to the use of stabilizer 15%. Two factors might lead this condition are, first, the stabilizer was added was uneven, and another one was that the reduction of water inside the peat pores inhibited or slowed down the reaction of silicate calcium gel formation [8, 10, 22]. The changes in the water content of peat soil were also affected by the curing duration especially in the beginning period of the stabilization (10 days). On the 20th day of the stabilization, the changes water content was not remarkable since water inside the pores continuously decreased while



(a)

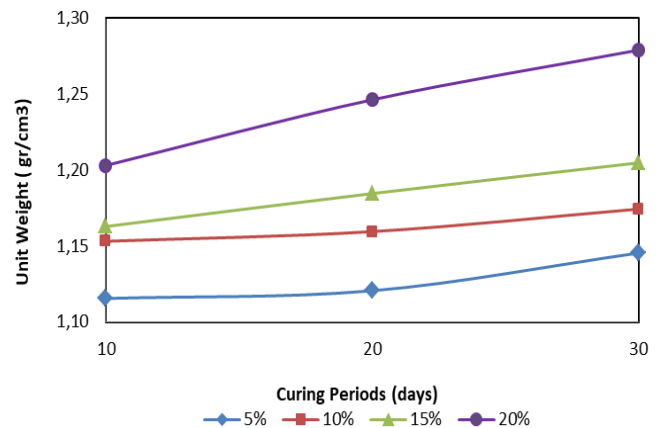


(b)

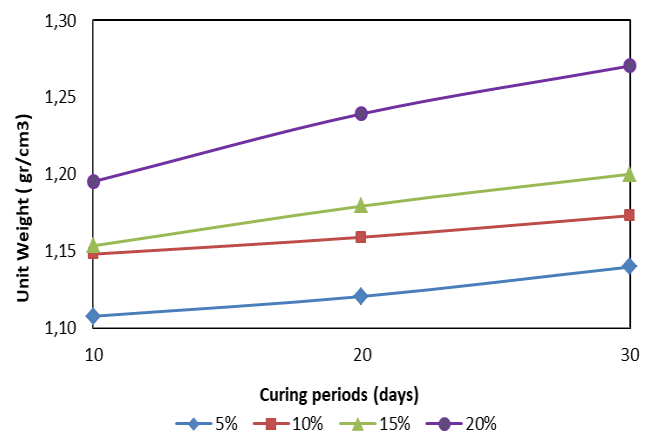
Figure 6: The changes in the water content of peat soil stabilized, a). Border parts; b) central parts

the water infiltration in surrounding area was slowing down as the result of material changes on peat as being stabilized. Even, after 20 days of stabilization, the water content remained constant. This behavior strengthens the previous argument that the amount of water in the

peat macropores is getting less and it inhibits reaction forms silicate calcium gel that covers fibers of peat and fills in the macro-pores of peat is being stabilized. Changes of water content in the observed spots in the border areas (Fig. 6a) and in the middle area (Fig. 6b) of peat stabilized did not also show significant difference water content. This shows that the condition of macropores of peat stabilized in its border and central parts had almost similar behavior. Its γ_t , the area of 30 cm stabilized peat had not caused any changes in water content. The addition of a stabilizer into fibrous peat soil increased the peat soil unit weight (Fig. 7). The higher the percentage of stabilizer added can increase Unit Weight of peat soil stabilized (γ_t). It was indicated by the γ_t value of peat soil with 20% of stabilizer achieved 1,2 gr/cm³ in the early period of stabilization (10 days). Although the quantity of water inside the peat pores continuously decreased during the formation of CaSiO_2 gel, the solid material of peat increased because the gel was formed could fill the pores and wrapped its fibers. The effect of stabilization duration also affected the value of γ_t . The longer the stabilization process takes place, the more increase the γ_t . The increase of γ_t value was caused by the reaction of gel formation which continuously developed although water supply inside macropores of peat was being stabilized getting slower.



(a)

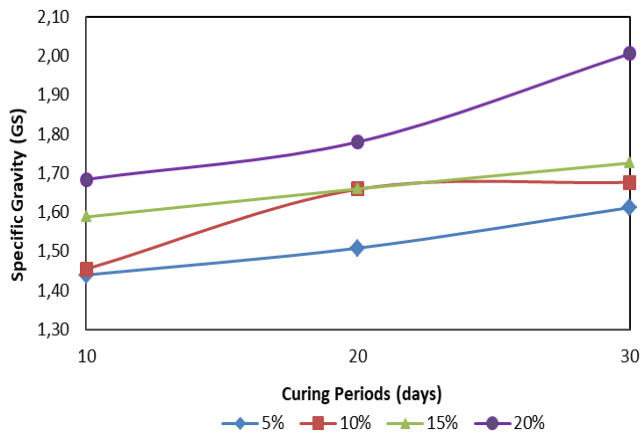


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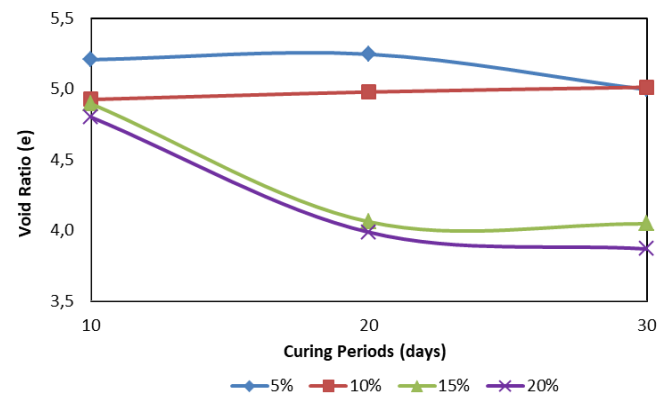
Figure 7: Changes in Unit Weight (γ_t) of peat soil stabilized a). Border area; b) central area

This behavior is in line with a study carried out by Mochtar, NE. [8] and Yulianto, FE., [23] stated that the gel continuous to grow until the 120th day of stabilization. However, the changes of γ_{ts} value in border (Fig. 7a) and middle areas of peat (Gambar 7b) stabilized were not as significant as the changes in water content. This phenomenon supports the previous statement that the stabilization area of 30cm has not given a different result from parameters of peat soil stabilized in some tested areas. Specific gravity (G_s) score in peat soil was in the range between 1,4 and 1,7 [4, 10]. G_s value of peat can increase to above 1,7 if the soil is mixed with mineral [4, 10]. That behavior is indicated by the value of G_s of peat stabilized with the admixture of lime CaCO_3 and rice husk ash (Fig. 8). G_s values of peat soil stabilized increased in the early period of stabilization (10 days) with the peat ratio of 15% and 20%, while in 5% and 10% of peat soil, the change of G_s score was still invisible and even lower than the value of G_s of initial peat soil. This was due to the amount of stabilizer was much lower and needed longer time to react to producing silicate calcium gel as the result of water infiltration in the surrounding areas. This behavior was also explained in the studies by Harwadi, FE., [3] and Mochtar, NE., [8].

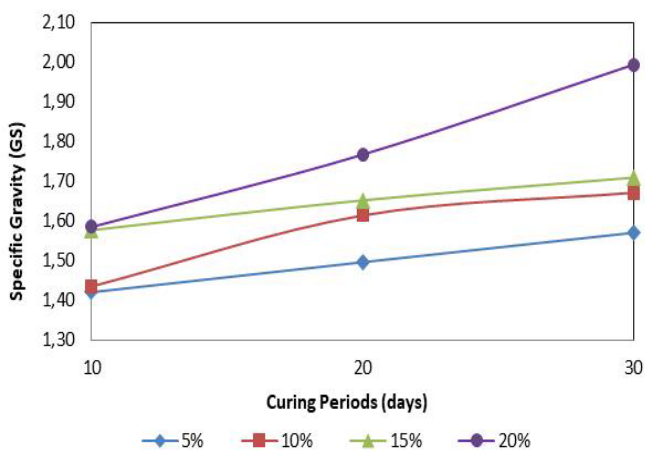
The longer the duration of the stabilization process, the higher the G_s value and it will reach 2,0 once it reaches 30 days. This behavior is different from peat soil is not affected by water infiltration surrounding it when being stabilized [6]. Peat soil without water infiltration obtained the value of G_s of 2,16. This shows that water infiltration highly affects the formation of silicate calcium gel and the change of peat parameter is stabilized. The G_s values in the border and middle areas of peat with various curing periods of stabilization did not also show remarkable differences. The reaction of silicate calcium gel formation in peat stabilized using CaCO_3 and rice husk ash is able to reduce the void ratio (Fig. 9). The gel was formed can fill the peat pores and wrap the fibers of peat stabilized. The higher the percentage of stabilizer was added, the smaller the void ratio because there was more silicate calcium formed. It was similar to the changes in water content. Changes in pores of peat stabilized show that the stabilizer with the percentage of between 15% and 20% produces better results than other percentages. This behavior indicates that stabilizer below 15% is still unable to form gel due to water infiltration in the surrounding area. The longer the duration of stabilization carried out on peat, the smaller the void pore because silicate calcium gel will continuously develop. This behavior can be seen



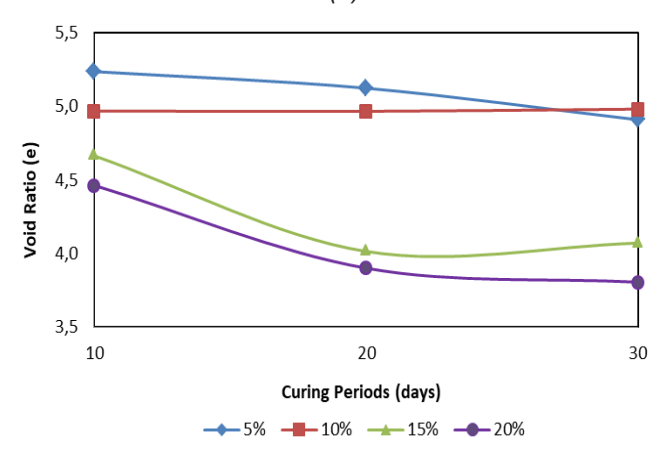
(a)



(a)



(b)



(b)

Figure 8: Changes in specific gravity (G_s) of peat soil stabilized on its, a). Border area; b) central area

Figure 9: Changes of void ratio (e) in peat soil stabilized, a). Border area; b) central area

in peat stabilized with 20% of stabilizer. In stabilization with 10% and 15% of stabilizer, changes of pores of peat stabilized have not been stable because the silicate calcium gel formation was still easy to be affected by water infiltration from surrounding areas. [10]. The formation of silicate calcium gel in peat soil caused the organic content to decrease (Fig. 10). This was a normal reduction caused by the increase of stabilizer reacting to form new solid granule of lime (CaSiO_3) filled and covered the pores of peat. The higher the quantity of stabilizer added, the more significant the decrease of organic content because there were also more CaSiO_3 formed. This behavior can be also seen in the change of γ_t value (Fig. 7) G_s (Fig. 8) and the void ratio (e , Fig. 9) at peat stabilized.

The use of 5% of stabilizer led the behavior of peat to show characteristics still as peat because the organic content is still above 75% [24]. The amount of organic content of peat was still high after being stabilized with 5% of stabilizer was caused by the inability of stabilizer to form CaSiO_3 gel. A significant change started to occur when the peat was stabilized with 10% of admixture as the value of O_c was already below 75% and the peat stabilized had been possible to be classified as non-organic soil. The value of O_c continuously decreased after the addition of more admixture and the lowest rate of O_c was found in the peat stabilized with 20% admixture. This behavior was an indication that peat with 20% of admixture produced the highest amount of CaSiO_3 gel. The change of O_c value was also affected by the curing period of peat stabilized. Corresponding to the behavior of other physical properties, the lowest O_c value was obtained on the 30th day of curing. While the effect of infiltration from the surrounding areas had not shown changes on O_c value of peat stabilized both in the border area (Fig. 10a) and in the central area of peat (Fig. 10b). It was possibly due to the period of stabilization was still within 30 days so that the reaction of CaSiO_3 gel formation had not been stable yet.

ENGINEERING CHARACTERISTICS OF PEAT SOIL STABILISED

Changes in physical characteristics of peat stabilized will absolutely cause changes in its engineering characteristics. Testing on engineering changes of peat studied was also carried out in the laboratory employing direct shear test to measure its carrying capacity and consolidation test to determine the decrease of peat soil. Fig. 11 shows the result of direct shear test on peat soil stabilized with different percentages of admixture and curing periods and different tested areas (border and middle parts). The shear strength of peat soil stabilized was getting bigger with the addition of a higher percentage of admixture. This condition occurred as the peat pores and fibers had been filled and wrapped with CaSiO_3 gel was formed after the chemical reaction occurred between admixture and water insides the peat pores. Peat soil with 5% of admixture experienced small change on its shear strength because the CaSiO_3 gel was formed was very

low and inadequate to contribute to the improvement of shear strength. Changes in shear strength started to be seen when the percentage of admixture added into the soil was above 5% (10%, 15% dan 20%).

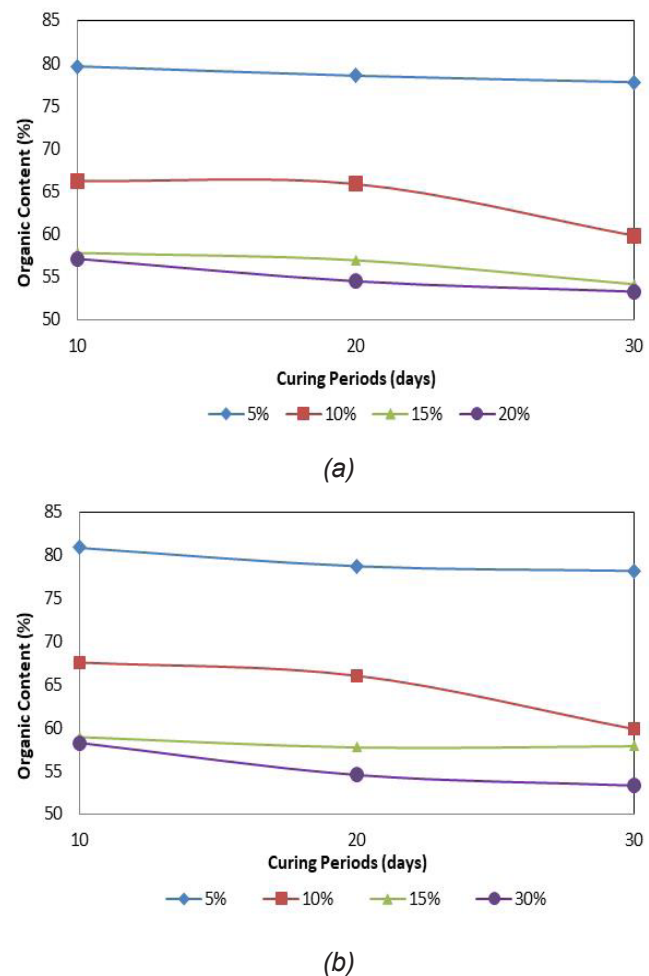
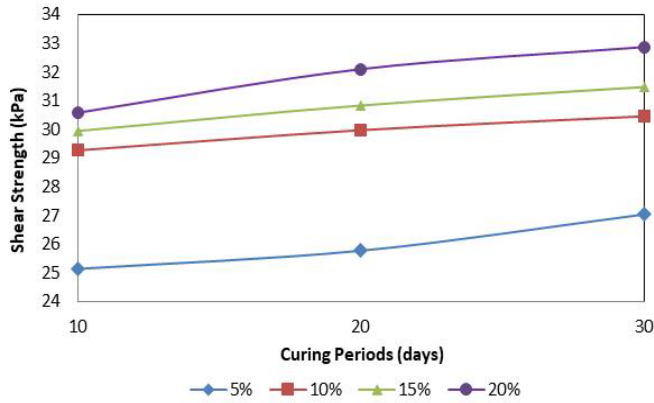


Figure 10: The changes of organic content of peat soil stabilized, a). Border area; b) central area

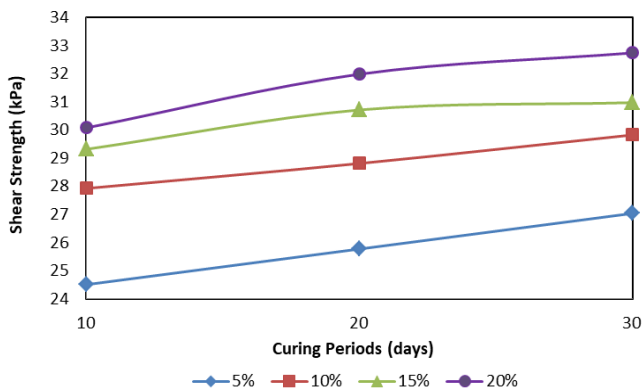
The gel was formed started to dominantly cover the pores of peat (Fig. 9) so that the shear strength continued to improve as the curing period got longer. Even, the shear strength was estimated to continue to increase based on the length of curing period as presented in the graph of shear strength change. Water infiltration on peat stabilized had not shown difference in its shear strength values. It can be seen from the shear strength value of border part (Fig. 11a) and the central part of peat stabilized (Gambar 11b). The value shear strengths in two different tested spots did not show significant differences and even were almost similar. This was caused by the process of CaSiO_3 gel formation was still continuing to occur. The behavior of this shear strength was also found in the parameters of other physical attributes (Fig. 7 and Fig. 8). The improvement of physical characteristics and shear strength of peat stabilized brought a big impact on the compression level (Fig. 12). At the beginning of curing period (≤ 10 days), the total compression occurred had not shown any significant changes be-

cause the CaSiO₃ gel had not been formed and was still unable to bear the weight working on peat stabilized. As the duration of curing process got longer, the behavior of total compression started to show a change in the percentage of admixture added into the peat soil. In general, the total compression gets lower when the percentage of admixture added increases.

cause the water infiltration reducing and slowing down. Although the addition of admixture led the physical properties especially its pores structure and organic content of peat stabilized to change, its compression behavior (based on consolidation test) remained the same with the initial condition (Fig. 13), because the pore structure of peat soil had not changed although the CaSiO₃ gel had wrapped the fibers and filled in the pores of peat stabilized



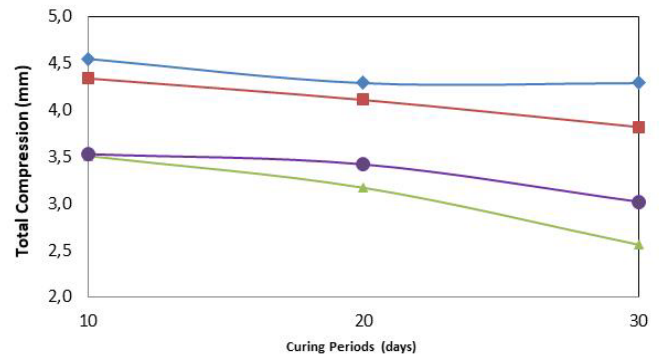
(a)



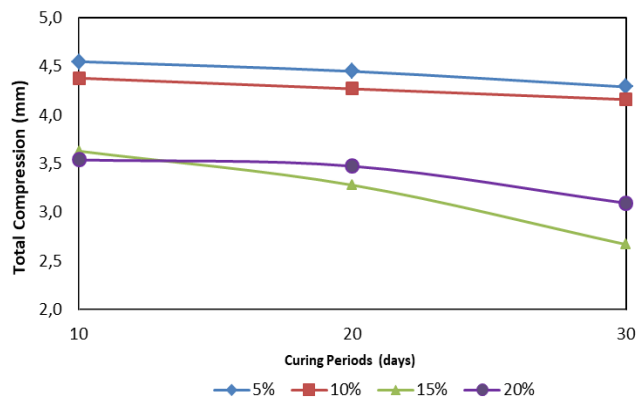
(b)

Figure 11: Changes of shear strength (τ) of peat soil stabilized, a). Border area; b) central area

Uncommon behavior was shown by peat stabilized using 15% of admixture. After 10 days of stabilization, the total compression occurred had better value than peat soil stabilized with 20% of admixture. This behavior was possibly caused by CaSiO₃ gel was formed in peat as it still needed water to react while water inside pores of peat continued to decrease (Fig. 7) causing the stability of gel in bearing weight for a quite long period was not achieved; this behavior also happened in some previous studies [7, 8]. Because the quantity of water inside pores continued to decrease, CaSiO₃ gel in peat with 15% of admixture had enough stability to bear consolidation weight. Harwadi, F [3] and Yulianto [6-8]) explained that a high percentage of admixture needs higher amount of water and longer duration so that the CaSiO₃ gel can have enough stability to support the load on it. While the water infiltration in its surroundings had not been able to give effect on the change of parameters of peat stabilized because the pores were getting smaller



(a)



(b)

Figure 12: The total compression of peat soil stabilized, a). Border parts; b) central parts

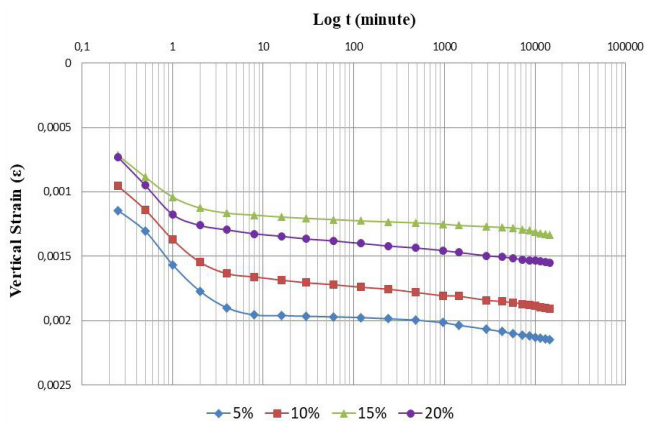


Figure 13: The behavior of compression of fibrous peat stabilized

CONCLUSIONS

From the description of the physical and engineering changes of peat stabilized using the admixture of lime (CaCO_3) and Rice husk ash, some conclusions can be withdrawn as follows:

1. The addition of admixture into fibrous peat causes the formation of CaSiO_3 gel fills pores and wraps the fibers of peat.
2. The formation of CaSiO_3 gel leads to the reduction of water content, while the Unit Weight and G_s increase, and void pore get smaller.
3. Changes in physical characteristics improve shear strength and reduce compression.
4. The formation of CaSiO_3 gel is highly affected by the condition of water inside peat pores so that the CaSiO_3 gel in peat with 20% admixture has not been totally stable in bearing weight due to the amount of water inside pores continuously reduces.
5. Water infiltration has not influenced the parameters of peat soil because the void pores continue to reduce causing the water flow slowing down.

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