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Behavior of High-plasticity Clay Stabilized with Lime and Rice Husk Ash

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Abstract

Soil is an important and fundamental element for building and road construction. However, poor properties of soil can affect the entire construction since the soil will resist the loads transferred from the upper structures. Additives such as cement, lime, and rice husk ash (RHA) can be used as stabilization materials to increase soil strength. This study examined the behavior of stabilized plastic clay mixed with cement, lime, and RHA. The clay stabilization success rate can be measured by the California Bearing Ratio (CBR), unconfined compression strength, and swelling potential. In this study, different mixtures were prepared as samples and tested under various loads: 1, 2, 3, 4, and 5 kPa. The results indicated that the addition of cement, lime, and RHA could effectively reduce the swelling potential of clay. The mixture variations of soil–cement composite 90% + RHA 10% and soil–cement composite 90% + lime 4% + RHA 6% showed the lowest swelling rate.

Abstrak

Perilaku Tanah Liat Plastisitas Tinggi yang Distabilkan dengan Kapur dan Abu Sekam Padi. Tanah merupakan element yang sangat penting dan mendasar bagi konstruksi bangunan dan jalan. Namun, karakteristik tanah yang buruk dapat mempengaruhi keseluruhan konstruksi dikarenakan tanah memiliki peran untuk menahan beban yang disalurkan dari struktur di atasnya. Studi ini mempelajari perilaku dari tanah lempung plastis yang distabilisasi dengan semen, kapur dan abu sekam padi. Tingkat keberhasilan stabilisasi lempung dapat diukur melalui pengujian California Bearing Ratio (CBR), Uji Tekan Bebas (UCS), dan potensi kembang tanah. Dalam studi ini, berbagai campuran dengan komposisi yang berbeda dibuat sebagai sampel dan diuji dengan beban yang bervariasi dari 1 kPa hingga 5 kPa dengan kelipatan 1 kPa. Hasil pengujian menunjukkan bahwa penambahan semen, kapur dan abu sekam padi efektif untuk menurunkan potensi kembang pada tanah lempung. Variasi campuran tanah semen 90% + abu sekam padi 10% serta variasi campuran tanah semen 90% + kapur 4% + abu sekam padi 6% menunjukkan tingkat kembang tanah yang paling rendah.

Keywords: additives, California bearing ratio, clay stabilization, rice husk ash, swelling

1. Introduction

Construction on high-plasticity clay is associated with several problems, including high shrinkage and differential settlement. These problems will occur if the clay directly interacts with water. The entry of water into the clay layer will reduce the soil shear strength and cause swelling. The properties of high-plasticity clay can be improved by the addition of several additives, such as cement, lime, fly ash, rice husk ash (RHA), salt, or Geosta, or a combination of additives.

Many rice-milling enterprises are located in the suburbs of the city, such as the Tambang District, Siak Sri Indrapura, and Riau Province. Rice husk is a waste product from rice mills. These husks turn into RHA

after they are dried and combusted. The RHA can be used as a component of organic fertilizers for agricultural lands. The RHA is rarely utilized in the construction and geotechnical fields, and the unused ash pollutes the soil, water, and air.

Local waste materials such as fly ash, bottom ash, and RHA have been widely researched as a component of soil mixture and have been found effective for increasing the soil shear strength and reducing soil plasticity. In this study, the performance of RHA as an additive of high-plasticity clay was compared with those of cement and lime. The characteristics of soil containing cement, lime, and RHA were also studied. This study mainly focuses on the plasticity and swelling potential of the samples.

Review of Literature. According to [1], soil structure is defined as the geometrical arrangement of soil granules. Some of the factors affecting soil structures are the soil shape, size, and mineral composition. In [2], it is stated that soil can be differentiated into two groups: non-cohesive soil and cohesive soil. High-plasticity cohesive soil has great potential to swell. In this case, soil stabilization is the most important preventive measure.

Soil stabilization is performed to improve soil shear strength and improve soil properties. Increased soil strength is reflected by the values of soil shear strength, swelling potential, and soil durability. Soil physical properties can be improved by reducing plasticity, reducing swelling and shrinkage, and increasing resistance to erosion and segregation.

Conventional soil stabilization by compaction cannot effectively change the nature of the soil shrinkage. Recently, there have been rapid improvements in soil stabilization technologies. One of such technologies is the mixing of the soil with additives or chemicals such as bitumen, fly ash, cement, lime, salt, engineering chemicals [3], clean set cement, Geosta, phosphoric acid, calcium acrylate, and calcium chlorite [4].

Several studies have been performed on RHA as a new material for soil stabilization. In [5], the effect of the addition of cement, RHA, and sugar cane bagasse ash on the swelling of expansive clay soil was investigated. The study considered additive percentages of 6% RHA + 4% cement and 6% cement + 8% sugar cane bagasse ash. The water content for each variation of the mixture was according to the standard Proctor test. The result indicated that the adopted materials can decrease the swelling rate of the expansive clay soil. The smallest swelling rate was obtained by field-condition soil + 4% cement.

In [6], the effect of lime addition on swelling was studied, considering lime percentages of 2.5%, 5%, and 7.5%. The addition of lime was found to decrease the swelling potential value. The highest decrease in swelling potential corresponded to 7.5% of lime.

2. Methods

Materials. High-plasticity clay samples were obtained from Muara Fajar, Pekanbaru, Indonesia. Portland cement produced by PT Semen Padang was used. The used lime was collected from samples produced by PT Brataco. Rice husk ash, the last additive, was obtained from Padang Sidempuan, North Sumatera, Indonesia.

Figure 1. Research Procedures

Preliminary test and main test. Samples with different compositions were prepared. Several tests were conducted on the samples. The samples were separated into two groups. Preliminary tests were conducted on soil specimens to obtain the soil properties. These include the Atterberg limit test and hydrometer test to determine the soil classification. Furthermore, a mechanical properties test, i.e., the standard Proctor test, was conducted to obtain the soil optimum moisture content (OMC) and the maximum dry density (MDD). The main test was the swelling test, which was conducted according to ASTM 4546-90. The test comprised a consolidation and swelling test (Geonor), considering four types of loads, and in one test, the swelling of a soaked sample was measured using a California Bearing Ratio (CBR) mold. Then a swelling test was performed after the sample achieved standard compaction. The sample was aged for 28 days. The next step was to prepare a sample in the consolidation ring for the swelling test. The swelling test began after the sample had been saturated for four days in a consolidation tool. The loads for the swelling test were set at 1.0 kPa, 2.0 kPa, 3.0 kPa, 4.0 kPa, and 5.0 kPa. The sample variations and research procedures are displayed in Figure 1.

3. Results and Discussion

Atterberg limit test. The Atterberg limit test results for various samples are presented in Table 1.

Based on the test results in Table 1, the addition of lime and RHA could effectively decrease the plasticity index of the samples; this means the soil could be stabilized through the addition. In this study, the samples with a total additive content of 10% were subsequently tested. This was because these samples had the lowest plasticity index.

Proctor test. The field-condition samples were subjected to a Proctor test to obtain the soil OMC and MDD. The results showed that the OMC and MDD of the sample were 29% and 13.7 kN/m³, respectively. The OMC result was used as the water content to create swelling samples.

Swelling test. A swelling test was conducted for several samples, mostly those with a total additive content of 10%. The results are presented in Table 2.

Table 1. Atterberg Limit test Results

No	Variation of Mixture	Atterberg Limit		
		LL (%)	PL (%)	PI (%)
1	Muara Fajar's clay (CH)	68.77	31.75	37.02
2	CH + cement 5% (CC)	63.15	37.92	25.23
3	CH + lime 4%	66.64	48.17	18.46
4	CH + lime 6%	62.51	42.17	20.34
5	CH + lime 10%	57.86	41.00	16.86
6	CH + RHA 4%	59.79	41.42	18.73
7	CH + RHA 6%	58.93	37.89	21.03
8	CH + RHA 10%	56.72	36.32	20.40
9	CC 90% + RHA 10%	59.10	35.56	23.54
10	CC 90% + lime 4% + RHA 6%	61.02	39.04	21.97
11	CC 90% + lime 6% + RHA 4%	57.85	43.64	14.21
12	Soil-cement composite (SCC) 90% + lime 10%	64.04	47.66	16.38

Table 2. Swelling test Results

Description	Free Swelling (%)				
	1.0 kPa	2.0 kPa	3.0 kPa	4.0 kPa	5.0 kPa
Field condition	1.50	0.43	0.13	0.04	0.01
CC 90% + RHA 10%	2.10	1.59	0.18	0.00	0.00
CC 90% + lime 4% + RHA 6%	2.05	1.68	0.18	0.00	0.00
CC 90% + lime 6% + RHA 4%	1.90	1.63	0.23	0.00	0.00
CC 90% + lime 10%	1.75	1.44	0.21	0.00	0.00

CC: clay cement, composed of 95% clay + 5% cement

RHA: rice husk ash

The effect of mixing soil samples with additives on the soil plasticity is illustrated in Figure 2. The soil consistency test result (Figure 2) showed a transition from high-plasticity clay to high-plasticity organic clay. This is because the organic ash in rice reduced the soil plasticity. Thus, the plasticity index and the liquid limit decreased. The effect of mixing soil samples with additives also influenced the soil swelling potential, as displayed in Figure 3.

Figure 2. Plasticity Graph of Samples

Figure 3 shows that when pressures of 4 kPa and 5 kPa were applied to the sample groups, the mixed soil samples no longer experienced swelling. This means that the load at 4 kPa and 5 kPa exceeded the magnitude of the expanding soil pressure. The swelling pressures of all soil variations were less than 4.0 kPa. Complete test results are presented in Tables 3 and 4.

Figure 3. Swelling Percentage

Table 3. Height Increment Due to Pressure Change

Description	1 kPa		
	Hi (mm)	Hf (mm)	ΔH (mm)
Muara Fajar's clay	20.00	20.30	0.30
SCC 90% + RHA 10%	20.00	20.42	0.42
SCC 90% + lime 4% + RHA 6%	20.00	20.41	0.41
SCC 90% + lime 6% + RHA 4%	20.00	20.38	0.38
SCC 90% + lime 10%	20.00	20.35	0.35
2 kPa			
Muara Fajar's clay	20.80	20.89	0.09
SCC 90% + RHA 10%	20.80	21.13	0.33
SCC 90% + lime 4% + RHA 6%	20.80	21.15	0.35
SCC 90% + lime 6% + RHA 4%	20.80	21.14	0.34
SCC 90% + lime 10%	20.80	21.10	0.30
3 kPa			
Muara Fajar's clay	119.60	119.75	0.15
SCC 90% + RHA 10%	119.60	119.81	0.21
SCC 90% + lime 4% + RHA 6%	119.60	119.81	0.21
SCC 90% + lime 6% + RHA 4%	119.60	119.88	0.28
SCC 90% + lime 10%	119.60	119.85	0.25
4 kPa			
Field-condition clay	21.30	21.31	0.01
SCC 90% + RHA 10%	21.30	21.30	0.00
SCC 90% + lime 4% + RHA 6%	21.30	21.30	0.00
SCC 90% + lime 6% + RHA 4%	21.30	21.30	0.00
SCC 90% + lime 10%	21.30	21.30	0.00
5 kPa			
Field-condition clay	21.00	21.00	0.00
SCC 90% + RHA 10%	21.00	21.00	0.00
SCC 90% + lime 4% + RHA 6%	21.00	21.00	0.00
SCC 90% + lime 6% + RHA 4%	21.00	21.00	0.00
SCC 90% + lime 10%	21.00	21.00	0.00

Table 4. Swelling Rate

Description	Percentage of free swelling decrease (%)	
	1 kPa	ε (%)
Muara Fajar's clay	1.50	71.15
SCC 90% + RHA 10%	2.10	24.45
SCC 90% + lime 4% +RHA 6%	2.05	17.92
SCC 90% + lime 6% + RHA 4%	1.90	13.97
SCC 90% + lime 10%	1.75	17.58
	2 kPa	ε (%)
Muara Fajar's clay	0.43	71.01
SCC 90% + RHA 10%	1.59	88.93
SCC 90% + lime 4% +RHA 6%	1.68	89.57
SCC 90% + lime 6% + RHA 4%	1.63	85.68
SCC 90% + lime 10%	1.44	85.51
	3 kPa	ε (%)
Muara Fajar's clay	0.13	70.05
SCC 90% + RHA 10%	0.18	97.33
SCC 90% + lime 4% +RHA 6%	0.18	100.00
SCC 90% + lime 6% + RHA 4%	0.23	100.00
SCC 90% + lime 10%	0.21	100.00
	4 kPa	ε (%)
Muara Fajar's clay	0.04	74.64
SCC 90% + RHA 10%	0.00	100.00
SCC 90% + lime 4% +RHA 6%	0.00	100.00
SCC 90% + lime 6% + RHA 4%	0.00	100.00
SCC 90% + lime 10%	0.00	100.00
	5 kPa	ε (%)
Muara Fajar's clay	0.01	99.89
SCC 90% + RHA 10%	0.00	100.00
SCC 90% + lime 4% +RHA 6%	0.00	100.00
SCC 90% + lime 6% + RHA 4%	0.00	100.00
SCC 90% + lime 10%	0.00	100.00

Based on Table 4, the decrease between the soil expansion ability at 3 kPa and that at 4 kPa was the largest. Therefore, the mixtures of soil, cement, RHA, and lime resisted pressures beyond 3 kPa. The original soil still expanded by 0.01% at a pressure of 5 kPa; thus, the different mixture variations had improved properties, compared with the original soil, which had a great swelling potential. Based on the above data, when all the soils were subjected to a load of 3 kPa, the mixtures of SCC 90% + RHA 10% and SCC 90% + lime 4% + RHA 6% exhibited the best performance, as they showed a smaller swelling rate than the other variations.

Table 2 and Figure 3 show that the pressure can still be reduced if the soil experiences swelling due to direct contact with water. The original soil swelling pressure of 5.0 kPa can be reduced by mixing the soil with additives such as RHA, lime, or lime + RHA. Mixing the clay with these ingredients at 10% reduced the

swelling rate by nearly 25%. The soil expansion ability at 4 kPa was lower than that at 3 kPa.

4. Conclusions

The addition of lime, RHA, and a combination of both could reduce the pressure of soil swelling. The addition of these components at 10% could reduce the swelling pressure by only 3.0 kPa. The optimal mixture amounts to reduce the soil swelling rate were 10% RHA and 4% lime + 6% RHA, which reduced the swelling rate by 24.45% and 17.92%, respectively.

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