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The Effect of Grain Size Distribution on Compression of Laterite Soil

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ABSTRACT

Laterite soil is often used as embankment soil in various civil constructions because this soil is widely available in South Kalimantan. However, it turns out that laterite soil is not suitable for use as embankment soil. This is because laterite soil has a fairly high plasticity index (PI) value, so improvement or stabilization efforts are needed to improve the soil quality.

In this research, a preliminary test was conducted to determine the physical and compression characteristics of the original laterite soil from Sungai Ulin, Landasan Ulin, and Mandiangin. After that, the main test was also carried out on laterite soil from the Sungai Ulin to determine the effect of the percentage of sands mixture in laterite soil on the consolidation parameters in the form of compression index (Cc), consolidation coefficient (Cv), swell index (Cs), coefficient of volume compressibility (mv), and permeability coefficient (k). The mixture of sand variation used in the test object is 0%, 7%, 14%, 21%, and 28%. Consolidated specimens were made with a density of 90% of the optimum moisture content.

The results of data analysis show that laterite soils from Sungai Ulin, Landasan Ulin, and Mandiangin are classified as Clay-High (CH) or high plasticity inorganic clays (fat clays). In addition, it is also known that laterite soil from Mandiangin has a higher compression index (Cc), swell index (Cs), and coefficient of volume compressibility (mv) than laterite soil from the Ulin River and Landasan Ulin. Meanwhile, laterite soil from the Sungai Ulin has a higher consolidation coefficient (Cv) and permeability coefficient (k) than laterite soil from the other two areas. Furthermore, data is obtained in the form of a graph showing the behavior of the mixture of sand fractions on the value of the compression index (Cc) and swell index (Cs) of laterite soils, when the percentage of the mixture of sand fraction increases, the values of the compression index (Cc) and swell index (Cs) decrease. The consolidation coefficient (Cv) also gets the effect by the percentage of the sand mixture. When the percentage of the mixture of the sand fraction increases, the value of the consolidation coefficient (Cv) also increases. The value of the coefficient of volume compressibility (mv) also decreases along with the increase in the percentage of the mixed sand fraction, the decreasing value is about 28.30%. In addition, the higher the percentage of mixed sand fraction in laterite soils, the value of the permeability coefficient (k) also increases, the increasing value is about 12.78%.

Keywords: laterite soil, compression of laterite soil, grain size distribution, sand fraction

1. INTRODUCTION

Generally, original soils in South Kalimantan are classified as soft soil types, so they often use embankment material in the form of laterite soil in civil construction, both in the form of roads and buildings. This is because laterite soils are easy to find and widely available in South Kalimantan. However, it turns out that this soil has a drawback if it is to be used as embankment soil, because it has a fairly high Plasticity Index (PI) value. Based on scientific research by Ilmi (2021), laterite soil from Cempaka, Banjarbaru City, South Kalimantan Province has a Plasticity Index (PI) value of 34.5%. According to the specifications from Bina Marga, the soil is not suitable for use as embankment material. This makes laterite soils still questionable regarding the quality and how appropriate the composition to be used as embankment soil is. Therefore, it is necessary to improve or stabilize the laterite soil mechanically or chemically so that the quality of the soil can be better. Efforts to improve or stabilize the lateritic soil must also be followed by paying attention to the consolidation settlement. This is because the consolidation process can increase the potential for damage to civil construction, especially on roads in South Kalimantan.

2. LITERATURE REVIEW

Laterite Soil

Lateritic soil is a type of soil formed from high-level weathering, and it is formed from the hydration concentration of aluminum and iron oxides (Amu et al., 2011). This laterite soil has various characteristics: there are hard, difficult to penetrate, and very difficult to change when in dry conditions (Makasa, 2004). Laterite soils consist of a variety of residual soils, there are red, brown to yellow, fine-grained residual soils with a light texture that have nodular grain shape and are well cemented (Lambe and Whitman, 1979).

Sand

Sand is *cohesionless soil*, coarse-textured, and characterized by the presence of large pore spaces between the grains (Craig, 1989). This condition causes the sand has a loose-grained nature. When sand is dried, the grains will separate. According to the Unified Classification System (USCS), it is said to be sand if more than half of the coarse fraction is between No.4 (4.75mm) and No.200 (0.075mm) of sieve sizes (Bowles, 1984).

Consolidation

The process of reducing the volume or reducing the pore voids of low-permeable soil caused by loading, where the process is influenced by the speed or time of squeezing of pore water out of the soil cavity is called consolidation (Hardiyatmo, 2002).

Consolidation consists of two main parts, there are primary consolidation and secondary consolidation. Primary consolidation is the settlement caused by changes in soil volume during the period of pore water discharge from the soil, where the pore water stress gradually shifts to effective stress as a result of the outflow of the pore water. Meanwhile, secondary consolidation is a decrease that occurs after all pore water pressure lost, where this consolidation is caused by compression that occurs due to plastic adjustments of the soil grains with a *time dependent process* (SNI 2812: 2011).

Parameters related to the process of consolidation based on ASTM D 2345, are as follows:

1) Compression Index (Cc)

The compression index value is used to obtain the amount of settlement that occurs due to consolidation that occurs in the soil. Soil compression index can be calculated by the following equation:

$$Cc = \frac{\Delta_e}{\Delta \log p'} = \frac{e_1 - e_2}{\log p_2' - \log p_1'} = \frac{e_1 - e_2}{\log \left(\frac{p_2'}{p_1'}\right)}$$

Description:

Cc = Compression index

e_1 = Void ratio at p_1’

e_2 = Void ratio at p_2’

p_1’ = Initial stress (cm^2/sec)

p_2’ = Final stress (cm^2/sec)

2) Consolidation Coefficient (Cv)

Consolidation coefficient is a parameter that relates changes in excess pore water pressure with time. The consolidation coefficient is used to determine the length of time the consolidation will take place and can also determine the level of decline that will occur. The value of the consolidation coefficient is determined using *square root of time method* with the formula:

$$C_v = \frac{Tv \times H^2}{t_{90}} = \frac{0{,}848 \times H^2}{t_{90}}$$

Description:

C_v = Consolidation coefficient (cm^2/sec)

0,848= Time factor (T_v) for 90% consolidation

H = ½ of the average height of the consolidation specimen with the top and bottom drainage (double drainage) (cm)

t_{90} = Time to reach 90% consolidation (sec)

3) Swell Index (Cs)

The swell index value is usually smaller than the compression index value and can be determined in the laboratory (Das, 1995). Generally, the value of the development index is as follows:

$$C_s = \frac{1}{5} \text{ to } \frac{1}{10} C_c$$

4) Coefficient of Volume Compressibility (mv)

Coefficient of volume compressibility is the change in volume per unit for each unit change in stress or as a ratio of volume change per unit increase in active stress on the soil. The coefficient of volume compression (mv) can be calculated by the formula:

$$m_v = \frac{\left(\frac{\Delta_H}{H_1}\right)}{\Delta_p} = \frac{\left(\frac{\Delta_V}{V_1}\right)}{\Delta_p} = \frac{a_v}{1 + e_1}$$

Description:
a_v = Compressibility coefficient
e_1 = Void ratio at p_1'

The Value of Permeability Coefficient (k) based on Consolidation Test

The value of permeability coefficient (k) can be determined based on the consolidation test results using the equation (ASTM D2345):

$$k = M_v.\gamma_w.C_v$$

Description:
k = Permeability coefficient (cm/sec)
mv = Coefficient of volume compressibility (cm^2/g)
Cv = Consolidation coefficient (cm^2/sec)
γw = The volume weight of water (g/cm^3)

3. RESEARCH METHODOLOGY

The testing steps in this research are as follows:

1) In the test preparation, there is the preparation of materials and equipment.
2) Sampling the laterite soil and sand in the field. Sampling the laterite soil in the field consists of two stages. The first stage was taking undisturbed and disturbed laterite soil at three locations in South Kalimantan, there are Sungai Ulin, Landasan Ulin, and Mandiangin as soil samples for preliminary testing. The second stage is taking disturbed laterite soil in the Ulin River as the main test soil sample. Then, sand was used as a stabilizing material in the main test. The sand is from the Barito River.
3) Preliminary tests were carried out on laterite soils from Sungai Ulin, Landasan Ulin, and Mandiangin covering physical and mechanical characteristics tests (water content test, volume weight test, specific gravity test, sieve analysis test, hydrometer analysis test, atterberg limit test, compaction test, and consolidation test).
4) Analysis of the results of testing the characteristics of laterite soils from the Sungai Ulin, Landasan Ulin, and Mandiangin.
5) Analysis of grain size analysis and atterberg limit on laterite soil from the Sungai Ulin with variations in the mixed sand fraction of 0%, 7%, 14%, 21%, and 28%.
6) Consolidated specimens were made on laterite soil samples from the Sungai Ulin with variations in the mixture of sand fractions of 0%, 7%, 14%, 21%, and 28%. Consolidated specimens were made using a maximum density of 90% of the optimum moisture content (OMC). The results of data analysis obtained from the consolidation test include the relationship between variations in the sand fraction mixture to water content (w), initial void ratio (e_0), compression index (Cc), consolidation coefficient (Cv), expansion index (Cs), volume compression coefficient (mv), and the coefficient of permeability (k).

4. RESULTS AND DISCUSSION

Physical Characteristics Test Results and Compression Characteristics on Original Laterite Soils from Sungai Ulin, Landasan Ulin, and Mandiangin

Physical characteristic tests of laterite soils carried out in the laboratory include sieve analysis, hydrometer analysis, water content test, density test (volume), specific gravity test, and atterberg limit test. The results of the physical characteristics test can be seen in Figure 1 and Table 1.

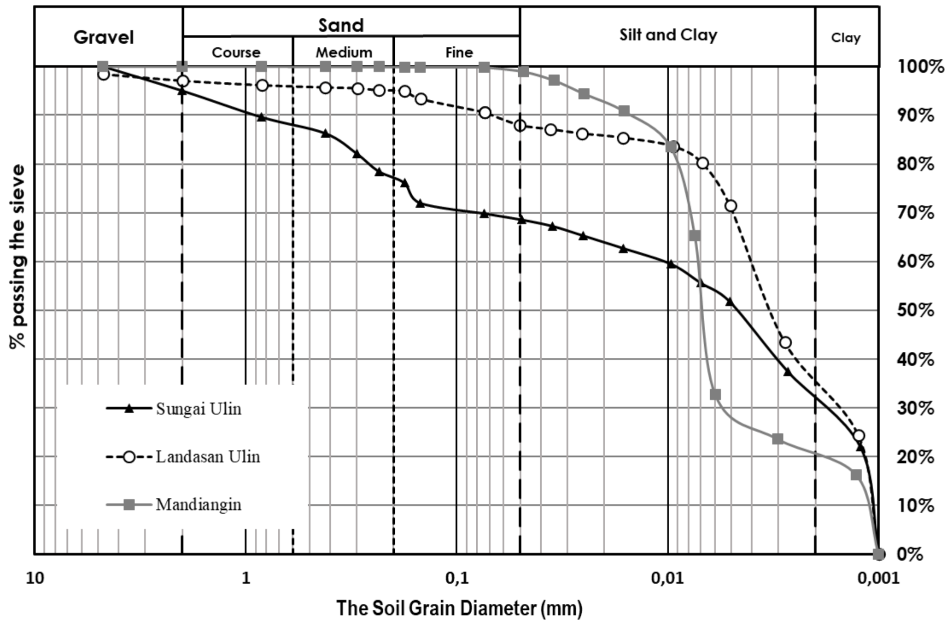

Figure 1. Graph of Grain Size Distribution of Original Laterite Soils from the Sungai Ulin, Landasan Ulin, and Mandiangin

Table 1. Physical Characteristics Test Results of Original Laterite Soils from Sungai Ulin, Landasan Ulin, and Mandiangin

Name of Sample				Laterite Soil from Sungai Ulin	Laterit Soil from Landasan	Laterit Soil from Mandiangin
The Physical Characteristics of Soil	*Soil Properties*	Spesific Gravity (Gs)		2,65	2,63	2,65
		Water Content (W)	%	31,41	37,82	54,03
		Volume Weight (ɣ)	gr/cm³	1,92	1,82	1,63
	Grain Size Distribution	Gravel (>2mm)	%	4,96	2,93	0,01
		Course Sand (0,6-2,00mm)	%	7,08	1,13	0,03
		Medium Sand (0,2-0,6mm)	%	10,65	0,89	0,06
		Fine Sand (0,05-0,2mm)	%	9,40	7,45	1,85
		Silt and Clay (0,002-0,05mm)	%	38,16	53,60	78,06
		Clay (<0,002mm)	%	29,76	33,99	19,97
		No. 10 (2,00mm)	%	95,04	97,07	99,99
		No. 40 (0,425mm)	%	86,32	95,71	99,94
		No. 200 (0,0075mm)	%	69,86	90,64	99,85
	Atterberg Limits	Liquid Limit (LL)	%	52,85	81,43	74,34
		Plastic Limit (PL)	%	23,68	33,91	32,67
		Plasticity Index (PI)	%	29,16	47,52	41,67
		Classification		CH	CH	CH

The test results of sieve analysis and analysis hydrometer on the original condition of undisturbed laterite soils from Sungai Ulin, Landasan Ulin, and Mandiangin show that the laterite soils in the three areas have a percentage value of grains passing the sieve No. 200 which is greater than 50%. Based on the value of the plasticity index (PI), lateritic soil from Landasan Ulin has a higher plasticity index (PI) value than laterite soil from Sungai Ulin and Mandiangin.

The liquid limit value (LL) and plasticity index (PI) of laterite soils in these three areas can be used to determine soil classification using the plasticity diagram of the USCS method as shown in Figure 2 below. Based on the diagram, it can be concluded that the laterite soil is classified as High Clay (CH) or high plasticity inorganic clay (fat clays).

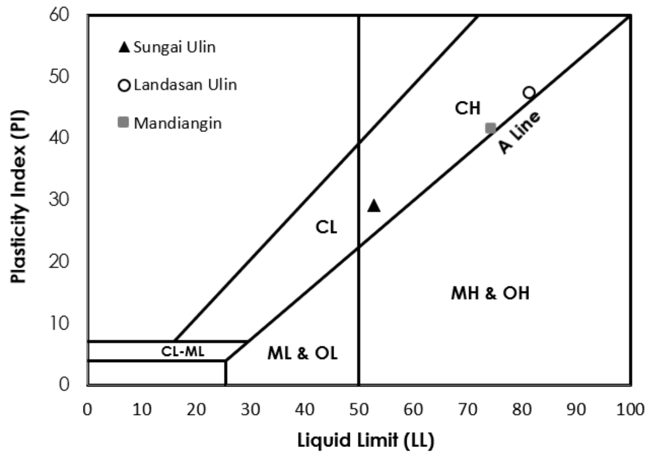

Figure 2. USCS Classification Diagram for Laterite Soils from Sungai Ulin, Landasan Ulin, and Mandiangin

The mechanical characteristics tests carried out in this preliminary test are compaction test and consolidation test. The results of mechanical characteristics test of original laterite soil from Sungai Ulin, Landasan Ulin, and Mandiangin River can be seen in Table 2 below.

Table 2. The Results of Mechanical Characteristics Test of Original Laterite Soils from Sungai Ulin, Landasan Ulin, and Mandiangin

Name of Sample				Laterite Soil from Sungai Ulin	Laterit Soil from Landasan Ulin	Laterit Soil from Mandiangin
The Mechanical Characteristics of Soil	*Compaction*	Optimum Moisture Content (OMC)	%	22,81	28,46	27,36
		Maximum Dry Weight (γdmaks)	gr/cm³	1,65	1,57	1,33
	Consolidation	Compression Index (Cc)		0,21289	0,32624	0,43613
		Consolidation Coefficient (Cv)	cm^2/sec	0,00018814	0,00014903	0,00012433
		Swell Index (Cs)		0,024149	0,039853	0,062585
		Coefficient of Volume Compressibility (mv)	cm^2/gr	0,01648087	0,02032832	0,02407538
		Permeability Coefficient (k)	cm/sec	3,10069E-06	3,02959E-06	2,99321E-06

Furthermore, the comparison of the average value of compression index (Cc), consolidation coefficient (Cv), swell index (Cs), coefficient of volume compressibility (mv), and permeability coefficient (k) of laterite soil from the Ulin River, Basa Ulin, and Mandiangin can be seen in Figures 3 to 7.

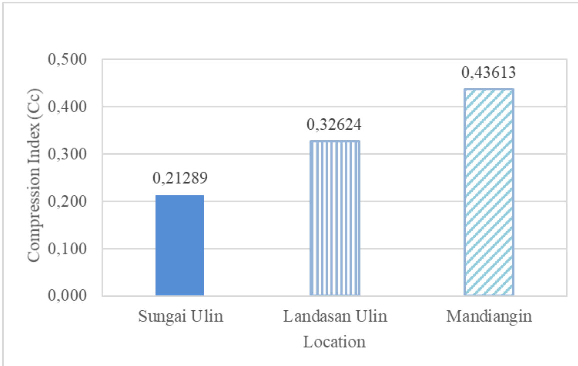

Figure 3. Diagram of the Average Compression Index (Cc) Values of Original Laterite Soils from Sungai Ulin, Landasan Ulin, and Mandiangin

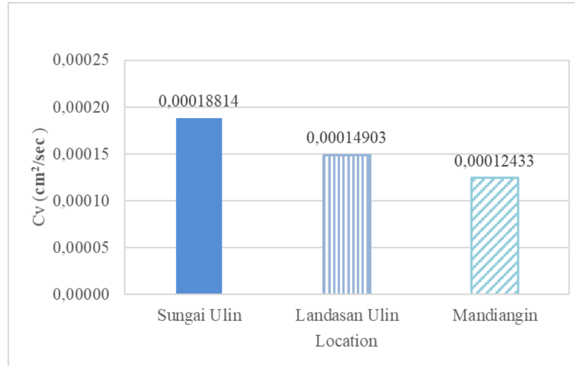

Figure 4. Diagram of the Average Consolidation Coefficient (Cv) Values of Original Laterite Soils from Sungai Ulin, Landasan Ulin, and Mandiangin

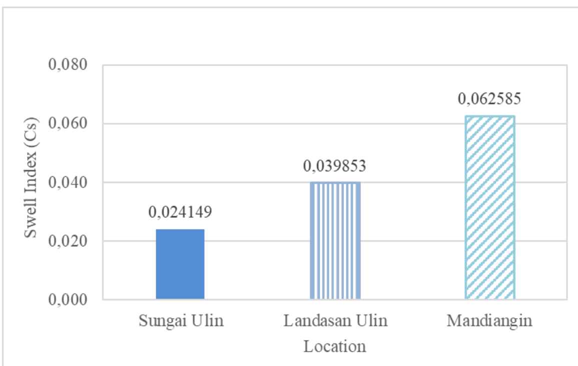

Figure 5. Diagram of the Average Swell Index (Cs) Values of Original Laterite Soils from Sungai Ulin, Landasan Ulin, and Mandiangin

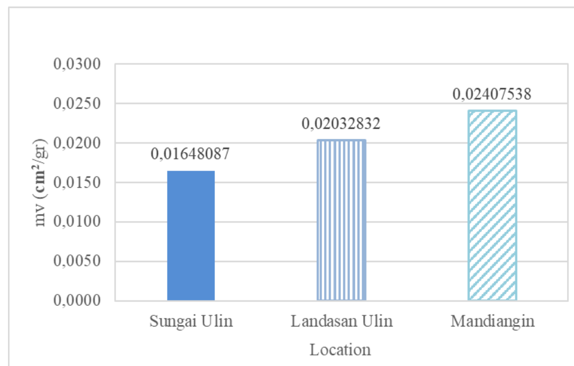

Figure 6. Diagram of the Average Coefficient of Volume Compressibility (mv) Values of Original Laterite Soils from Sungai Ulin, Landasan Ulin, and Mandiangin

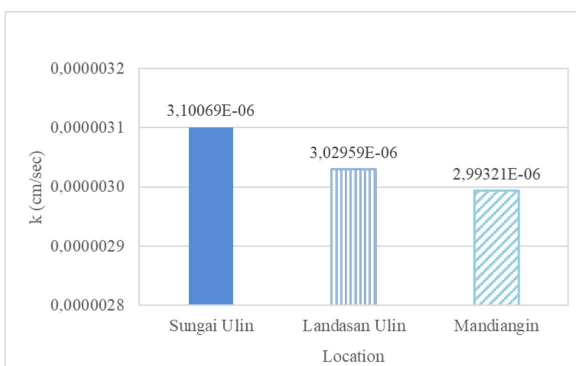

Figure 4. Diagram of the Average Permeability Coefficient (k) Values of Original Laterite Soils from Sungai Ulin, Landasan Ulin, and Mandiangin

Based on the consolidation test, it was found that laterite soil from Mandiangin had a higher compression index (Cc), swell index (Cs), and coefficient of volume compressibility (mv) compared to laterite soil from Sungai Ulin and Landasan Ulin. Furthermore, it was also found that laterite soil from Sungai Ulin had a higher consolidation coefficient (Cv) and permeability coefficient (k) than laterite soil from Landasan Ulin and Mandiangin.

The Test Results of Grain Size Analysis with Variations of Sand Fraction Mixture

The test results of the grain size analysis of laterite soil with variations of sand fraction mixture can be seen in Figure 8 and Table 3 below.

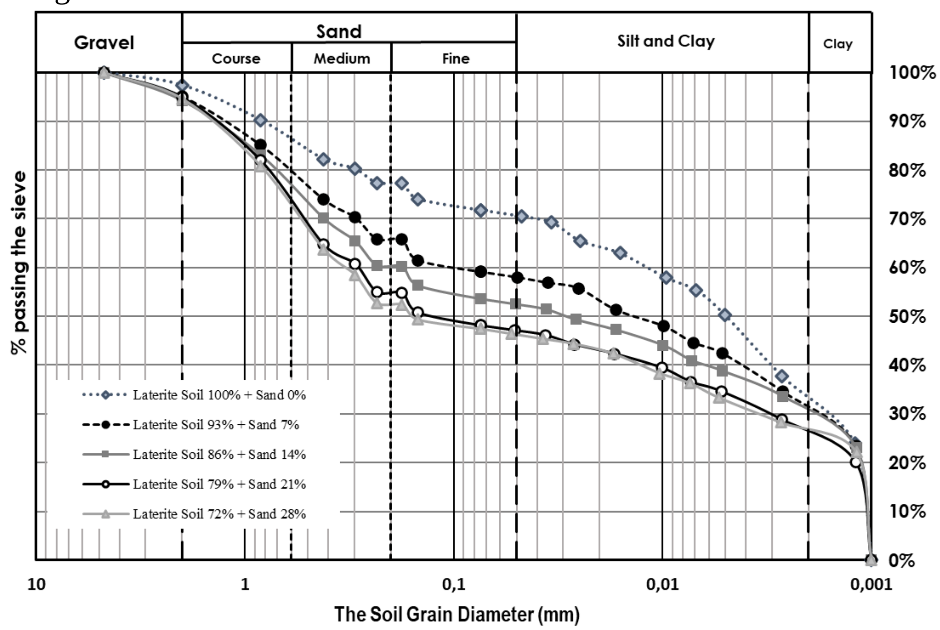

Figure 8. Graph of Grain Size Distribution of Laterite Soil with Variations of Sand Fraction Mixture

Table 3. Results of Grain Size Analysis of Laterite Soil with Variations of Sand Fraction Mixture

Grain Size		Laterite Soil 100% + Sand 0%	Laterite Soil 93% + Sand 7%	Laterite Soil 86% + Sand 14%	Laterite Soil 79% + Sand 21%	Laterite Soil 72% + Sand 28%
Gravel (>2mm)	%	2,60	4,93	5,73	5,07	5,37
Course Sand (0,6-2,00mm)	%	11,18	15,57	17,70	21,62	22,35
Medium Sand (0,2-0,6mm)	%	8,90	13,70	16,22	18,40	19,73
Fine Sand (0,05-0,2mm)	%	7,47	8,37	8,39	8,26	6,66
Silt and Clay (0,002-0,05mm)	%	39,01	28,43	23,62	22,13	20,67
Clay (<0,002mm)	%	30,83	28,99	28,34	24,53	25,21
No. 10 (2,00mm)	%	97,40	95,07	94,27	94,93	94,63
No. 40 (0,425mm)	%	82,20	73,93	70,10	64,70	63,77
No. 200 (0,0075mm)	%	71,73	59,10	53,53	48,10	47,40

Based on the test results of grain size analysis, it is shown that as the mixture of sand fraction in laterite soil increases, the coarse grain fraction increases and the fine grain fraction decreases. In addition, the higher the percentage of the sand mixture in the laterite soil, the percentage of laterite soil that passes the sieve No. 200 is getting smaller.

The Results of Atterberg Limit Test with Variations of Sand Fraction Mixture

Atterberg limit tests were carried out on laterite soils with variations of sand fraction mixture, including liquid limit test and plastic limit test so that the value of the plasticity index (PI) is known. The relationship between the variation of sand fraction mixture and the plasticity index value can be seen in Figure 9 below.

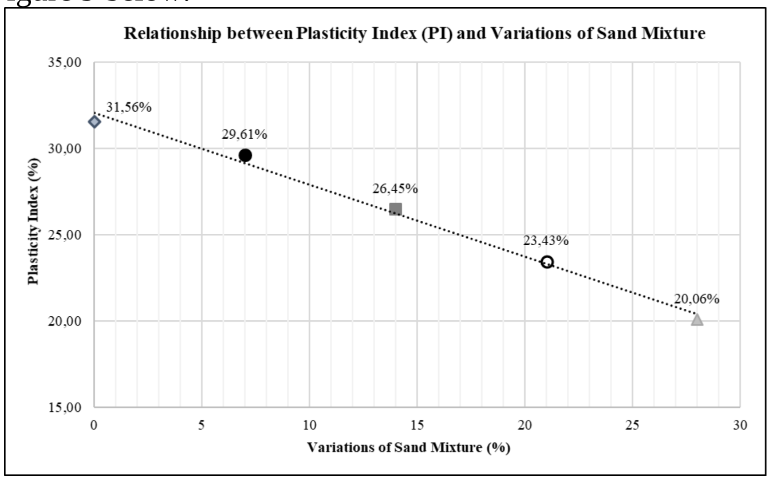

Figure 9. Graph of Relationship between Variations of Sand Fraction Mixture and Plasticity Index (PI)

Based on the graph above, it can be seen that the plasticity index (PI) value decreases as the percentage of sand fraction increases.

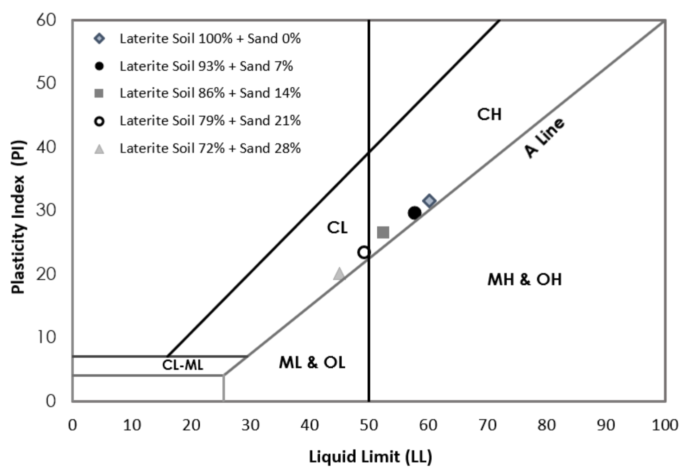

Figure 10. USCS Plasticity Diagram for Laterite Soils with Variations of Sand Fraction Mixture

USCS plasticity diagram for laterite soils with variations of sand fraction mixture in Figure 10 above shows that the classification of laterite soils which were originally grouped as *high plasticity* (CH) clays changed to l*ow plasticity* (CL) clays along with the addition of the percentage of sand fraction in the soil sample.

The Results of Consolidations Test with Variations of Sand Fraction Mixture

The consolidation test in this main test was carried out on laterite soil samples from the Sungai Ulin with variations of sand fraction mixture there are 0%, 7%, 14%, 21%, and 28%. The initial condition of all test specimens is a maximum density of 90% of the optimum moisture content.

1) Analysis of the Relationship between Variations of Sand Fraction Mixture and Water Content (w)

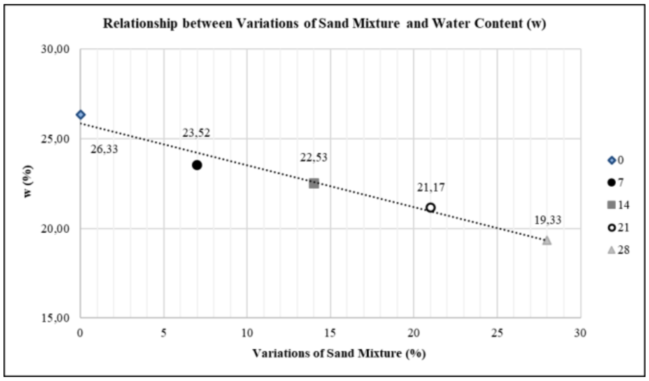

Figure 11. Graph of Relationship between Variations of Sand Fraction Mixture and Water Content (w)

Figure 11 shows that the higher percentage of the sand fraction mixture, the percentage of the water content (w) will decrease. The decrease in the water content (w) reached 26.68%.

2) Analysis of the Relationship between Variations of Sand Fraction Mixture and Initial Void Ratio (e_0)

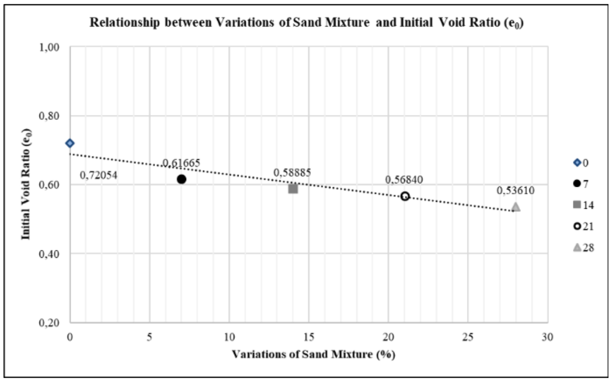

Figure 12. Graph of Relationship between Variations of Sand Fraction Mixture and Initial Void Ratio (e_0)

Figure 12 shows that the higher percentage of the sand fraction mixture, the higher the initial void value (e_0) will decrease even more. The decrease in the initial void ratio (e_0) that occurred reached 25.60%.

3) Analysis of the Relationship between Variations of Sand Fraction Mixture and Compression Index (Cc)

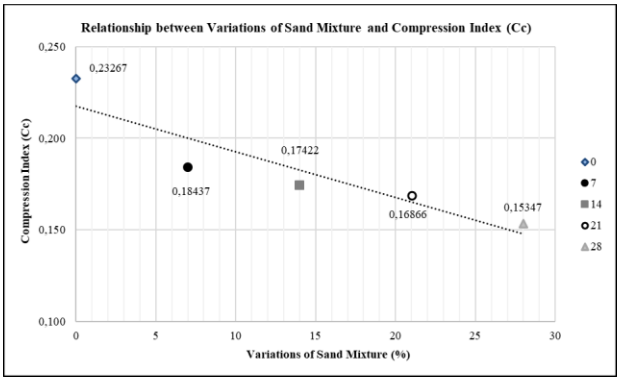

Figure 13. Graph of Relationship between Variations of Sand Fraction Mixture and Compression Index (Cc)

Based on the graph above, it shows that as the percentage of the sand fraction mixture increases, the value of the compression index (Cc) decreases. That means that the percentage of the sand fraction mixture is inversely proportional to the value of the compression index (Cc).

4) Analysis of the Relationship between Variations of Sand Fraction Mixture and Consolidation Coefficient (Cv)

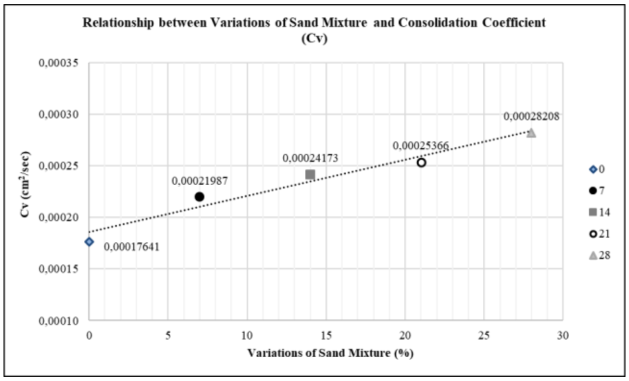

Figure 14. Graph of Relationship between Variations of Sand Fraction Mixture and Consolidation Coefficient (Cv)

Based on Figure 14, along with the increase in the percentage of sand fraction mixture, the value of the consolidation coefficient (Cv) also increases. This shows that the increase in the percentage of the sand fraction mixture is directly proportional to the value of the consolidation coefficient (Cv).

5) Analysis of the Relationship between Variations of Sand Fraction Mixture and Swell Index (Cs)

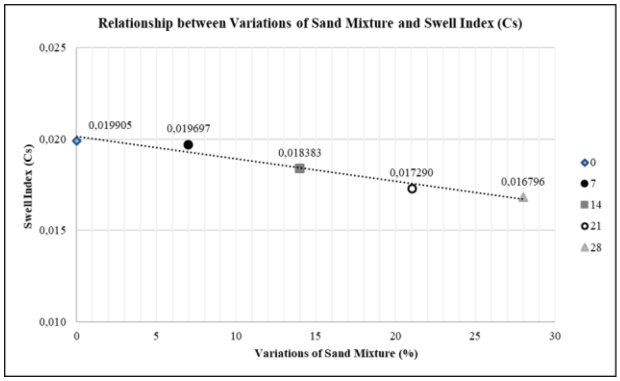

Figure 15. Graph of Relationship between Variations of Sand Fraction Mixture and Swell Index (Cs)

Figure 15 above shows that by increasing the percentage of sand fraction mixture, the value of the swell index (Cs) will decrease. That shows that the percentage of sand fraction mixture is inversely proportional to the swell index (Cs).

6) Analysis of the Relationship between Variations of Sand Fraction Mixture and Coefficient of Volume Compressibility (mv)

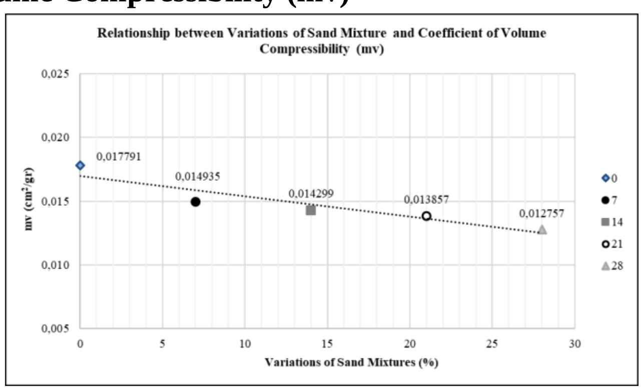

Figure 16. Graph of Relationship between Variations of Sand Fraction Mixture and Coefficient of Volume Compressibility (mv)

Graph above shows that the higher the percentage of the sand fraction mixture, the value of the volume compression coefficient (mv) will decrease. That shows the percentage of sand fraction mixture is inversely proportional to the coefficient of volume compressibility (mv). The decrease in the value of the coefficient of volume compressibility (mv) reached 28.30%.

7) Analysis of the Relationship between Variations of Sand Fraction Mixture and Permeability Coefficient (k)

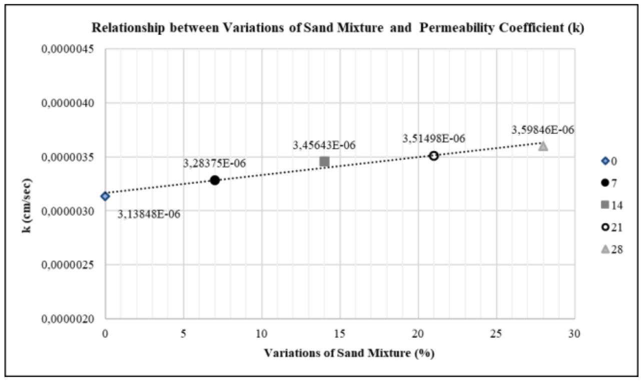

Figure 17. Graph of Relationship between Variations of Sand Fraction Mixture and Permeability Coefficient (k)

Figure 17 shows that the higher the percentage of sand fraction mixture, the value of the permeability coefficient (k) also increases. That shows the percentage of sand fraction mixture is directly proportional to the coefficient of permeability (k). When the sand fraction mixture is 0%, the coefficient of permeability (k) is 3.13848×10-06 cm/sec. Then this value continues to increase along with the increase in the percentage of sand fraction mixture, when the sand fraction mixture is 28%, the value of the permeability coefficient (k) becomes 3.59846×10-06 cm/sec. Based on these values, the increase in the value of the permeability coefficient (k) is 12.78%.

5. CONCLUSION

Based on the results and discussion, the following conclusions can be drawn:

1) Laterite soils from Sungai Ulin, Landasan Ulin, and Mandiangin are classified as *Clay-High* (CH) or high plasticity inorganic clays (*fat clays*) according to the USCS method. Based on the consolidation test, it was found that laterite soil originating from Mandiangin had a higher compression index (Cc), expansion index (Cs), and volume compression coefficient (mv) compared to laterite soil from Sungai Ulin and Landasan Ulin. Furthermore, it was also found that laterite soil from Sungai Ulin had a higher consolidation coefficient (Cv) and permeability coefficient (k) than laterite soil from Landasan Ulin and Mandiangin.
2) The results of the grain size analysis showed that as the mixture of the sand fraction in the laterite soil increased, the coarse grain fraction increased and the fine grain fraction decreased.
3) Based on the results of the consolidation tests analysis that have been carried out in this final project, it was found that the increase in the percentage of the mixed sand fraction was inversely proportional to the value of the compression index (Cc) and the expansion index (Cs). If the percentage of mixed sand fraction in lateritic soils increases, the compression index (Cc) and expansion index (Cs) will decrease. Furthermore, it was found that the increase in the percentage of the mixed sand fraction was directly proportional to the value of the consolidation coefficient (Cv). If the percentage of mixed sand fraction in lateritic soils increases, the value of the consolidation coefficient (Cv) also increases.

4) The percentage of the mixed sand fraction affects the coefficient of volume compression (mv) in laterite soils. When the percentage of the mixed sand fraction in laterite soils increases, the coefficient of volume compression (mv) decreases. The percentage decrease in the coefficient of volume compression (mv) along with the increase in the percentage of mixed sand fraction in laterite soils reached 28.30%.
5) The value of the permeability coefficient (k) of laterite soil when the mixture of the sand fraction is 0% reaches 3.13848×10^{-06} cm/sec. This value continues to increase along with the increase in the percentage of the mixture of sand fractions, when the mixture of sand fractions is 28%, the value of the permeability coefficient (k) becomes 3.59846×10^{-06} cm/sec. Thus, along with the increase in the percentage of the mixed sand fraction in laterite soils, it was found that the value of the permeability coefficient (k) increased by 12.78%.

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