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Embankment Stability on the Effect of Rainwater Infiltration on Clay Shale Laminated Soil

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Abstract—*Construction safety is one of the main issues that need to be considered in nowadays construction industries, for instance, is in Toll Road Construction. Balikpapan - Samarinda Toll Road Construction that planned to constructed through 99.02 km. At the embankment on Sta. 06+300 the slope goes through failure. In terms of structural geology, one of the main cause of slope failure is because the construction site categorized as the kampungbaru formation. The kampungbaru formation is formed from clay shale which immensely vulnerable to climate change and weather so it can reduce the shear strength of the soil. The purpose of this research is to analyze the influence of water content on clay shale's shear strength and analyze the effect of rainfall infiltration on slope stability and recommend suitable slope improvement for the site. In this study, laboratory tests were conducted to determine the properties of clay shale, analyze safety of factor (SF) using SLOPE / W for embankment without rainwater infiltration, and analyze safety of factor (SF) using SEEP / W and SLOPE / W for embankment with the influence of rainwater infiltration. The results of the laboratory tests show that the research location is on the clay shale soil layer due to laboratory results that proved the percentage of water content is in contrary with the shear angle and soil cohesion. The results show that rainwater infiltration affects the SF value. SF value without rainwater infiltration is 1.337 whereas SF value with rainwater infiltration is 0.907. The rainwater infiltration effect could decrease soil strength causing slope to become unstable. One of the suitable recommendations of soil improvements that can be chosen is chemical stabilization by adding lime additives. From the previous studies, the optimum percentage to add lime additives is 12%.*

Keywords— *Clay shale, shear strength, Geostudio 2018, rainwater infiltration, soil improvement.*

I. INTRODUCTION

According to the geological map of the Samarinda, the area of Balikpapan Toll Road Construction - Samarinda site is on the kampungbaru formation that formed from clay shale. Clay shale leads to many issues in the road construction both technical and non-technical problems. One of the technical problems that already happened was land subsidence/landslide at Sta. 06+500 location of the Balikpapan – Samarinda Toll Road Trace. This problem was occurred due to the road that constructed above clay shale soil.

Shale is a sedimentary rock with fine-sized particles formed from silt compaction and clay-size minerals that categorized as clay stone. It is one of the most complex and problematic geological materials. Clay shale soil is vulnerable to climate and weather changes. This can lead to fissures and soil weathering on the ground surface rubbing directly with air. This weathering process will decrease the shear strength of soil. Landslide in the Cipularang West Java Toll Road embankment was caused by the small shear strength of the clay shale layer underneath [2].

Hence, this research aimed to determine the effect of water content on shale shear strength of clay shale soil, analyze the effect of rainwater infiltration on slope stability and analyze the soil improvement of the unstable slope by lime additive with the percentage refer to the previous research [7].

II. THEORETICAL BASIS

A. Clay Shale

Shale is a sedimentary rock with fine-sized particles formed from silt compaction and clay-size minerals. It is included in the sedimentary rock category as a clay stone. In general, it consists of a laminated thin layer with irregular factions which is very slippery, fissile, and easily separated along the laminated plane. Clay shale can be found in lakes and lagoon deposits, river deltas, floodplains, and beaches. The clay shale will be soft clay soil like mud after exposure to sunlight, air, and water in a relatively short time.

Weathering is a change process in rocks on or near earth surface by chemical decomposition and physical disintegration. Clay shale soil is highly vulnerable to climate and weather changes. This can lead to fissures and soil weathering in areas directly exposed to air or water friction. The weathering on the clay shale soil caused by the air or water friction that could lead to the decreasing of shear strength resulting in landslide [1].

Analyzed mineral compositions of clay shale soil as shown in TABLE I by performing X-Ray Diffraction testing for each clay shale soil layer depth. The clay mineral compositions contained in the clay shale were kaolinite, illite, and montmorillonite while the non-clay minerals were calcite, quartz, and feldspar with different mineral composition percentage in each depth [2].

TABLE I. Tuban formation clay shale soil mineral composition.

		Mineral Composition (%)			
		Depth 10	Depth 12	Depth 14	Depth 16
Clay minerals	Kaolinite	19.1	25.2	-	18.4
	Illite	31.4	49.7	61.7	66.6
	Montmollonite	1.9	0.7	2	0.9
Instead of clay minerals	Calcite	18	-	-	-
	Quartz	29.6	24.4	36.3	14.2
	feldspar	-	-	-	-

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B. Slope

Slope is an edge located between runway and ramp. There are three kinds of slope, namely natural slopes, original soil artificial slopes, and compacted soil artificial slopes. Landslide can occur in any kind of slope due to the soil weight itself, coupled with the great effect of groundwater seepage as well as external force [4].

Slopes can occur naturally or artificially. If the ground surface is not flat, then the weight of soil parallel to the slope's gradient will cause the soil to move downward as in Fig. 1. If the weight of soil component is sufficiently large, in the a-b-c d-e-a zone can slip down that caused slope failure. In other words, the force that acts on the slope surpass the shear forces along the landslide plane.

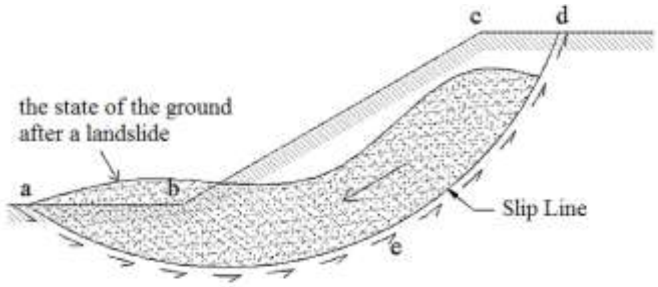

Fig. 1. Sliding slope.

C. Soil Water Characteristics Curve (SWCC)

Soil-Water Characteristic Curve (SWCC) is a relationship curve between water content and soil suction. The water content in the soil is usually measured in gravimetric water content (w), saturation level (S), or water content volume (θ). For soil suction plotting, the suction matrix is used in the lower suction range and total suction in higher suction vapors. The suction matrix and the total suction variable can be the same in high suction conditions (eg> 3000 kPa) [6].

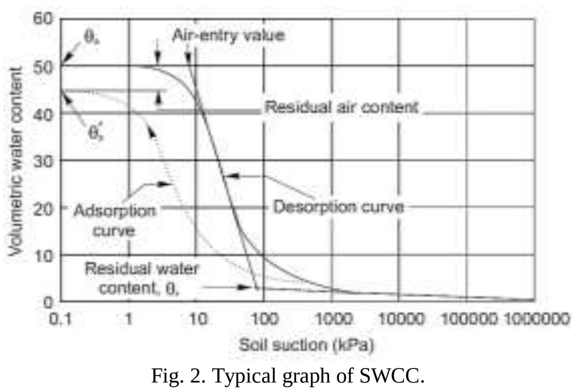

Fig. 2. Typical graph of SWCC.

SWCC is commonly used to describe the relationship between matrix suction and water content (such as gravimetric water content, volumetric water content and saturation level) of unsaturated soil. SWCC has a critical role in predicting mechanical properties, permeability parameters, and shear strength of unsaturated soil [5].

III. RESEARCH METHOD

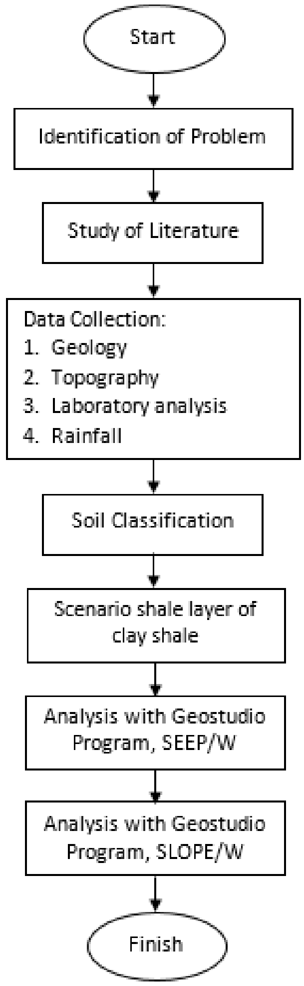

Fig. 3. Research flow chart.

The first process that needs to be done in this research is the identification of problems. The next step is the literature study to collect literature related to problem-solving, data collection such as geological data, topography data, laboratory analysis data, and rainfall data. Site's data obtained from the survey and investigation, while other databases obtained from the authorities. The final step is calculation analyze with two-dimensional software, Geostudio 2018.

A. Research Site

The location of research site was the Balikpapan – Samarinda Toll Road Project at Sta. 06+500, East Kalimantan, located in Package 2 Toll Road entering into Samarinda map area.

B. Research Data

The required data for the research were as follows:

1) Geological data
2) Topographic data
3) Rainfall data
4) Soil parameter data

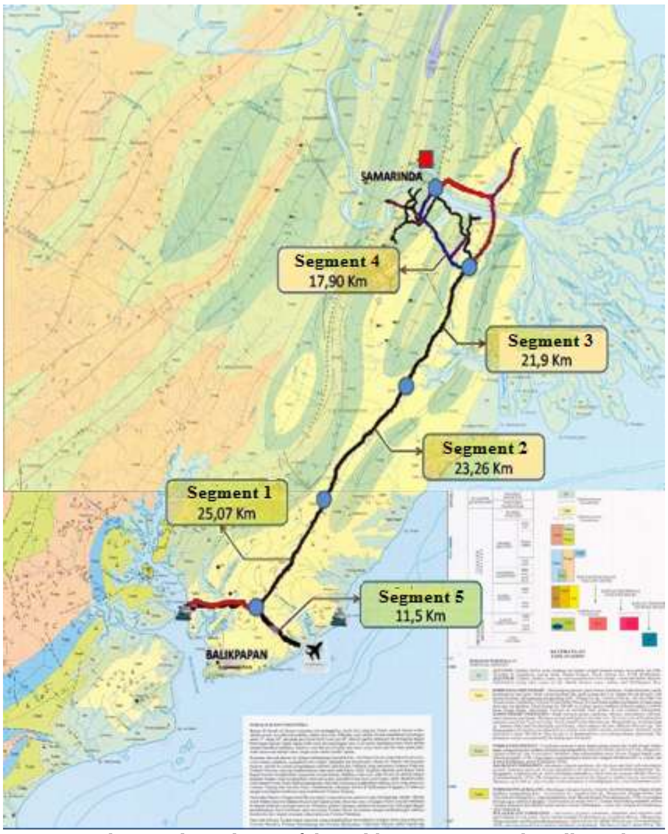

Fig. 4. Sheet geological map of the Balikpapan-Samarinda Toll Road.

C. *Safety of Factor Analysis*

Safety of Factor (SF) analysis using Geostudio 2018 software. For embankment without rainwater infiltration, SLOPE / W is used for SF analysis, while SEEP / W and SLOPE / W are used for embankment with rainwater infiltration effect. SF analysis was also performed for landfill repair, with chemical stabilization using 12% calcium additives.

IV. Results and Discussion

Some steps to be taken in analyzing the safety of factor for the slope, as follows.

A. *Soil Testing*

For soil classification, some laboratory tests are conducted to analyze the grain size and Atterberg limit. Grain size test graph is shown in

Fig. 5. It showed on the figure, the percentage of distribution that pass sieve no. 200 is 98.13%, this indicates that the soil is categorized as fine grain.

The value of liquid limit equal to 49.10% and plastic limit equal to 22,24% based on Atteberg limit. So the value of plasticity index (IP) is 26.86%. Based on the AASTHO classification, the soil research classified as classification A 7-6 (clay soil).

B. *Clay Shale Properties*

Clay shale is vulnerable to climate change and weather, thus it can lead to fissures and soil weathering on the surface of the soil that directly rubs against the air. This weathering process will reduce the shear strength. The continuous decrement of shear strength could potentially make the slope failure.

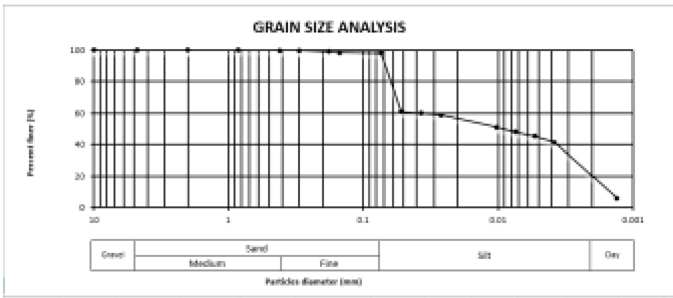

Fig. 5. Graph of grain size analysis.

The decrease in the shear strength due to water content change can be proved by Triaxial testing (ASTM D2850-70). The testing was performed by doing several treatment variations on the soil samples, distinguished by different water contents of 25%, 28%, and 30%. The triaxial test results are shown in Fig. 6 and Fig. 7.

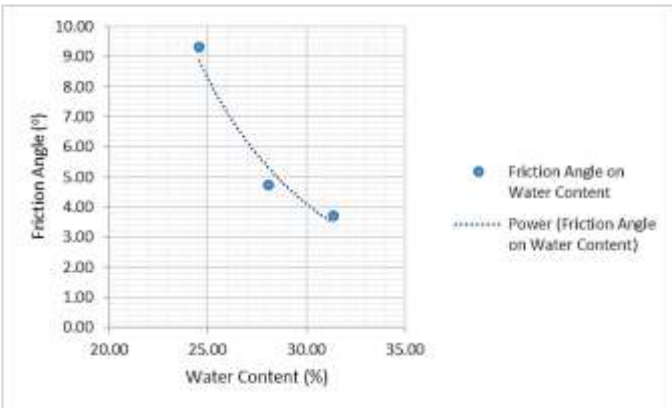

Fig. 6. Friction angle on water content by triaxial testing.

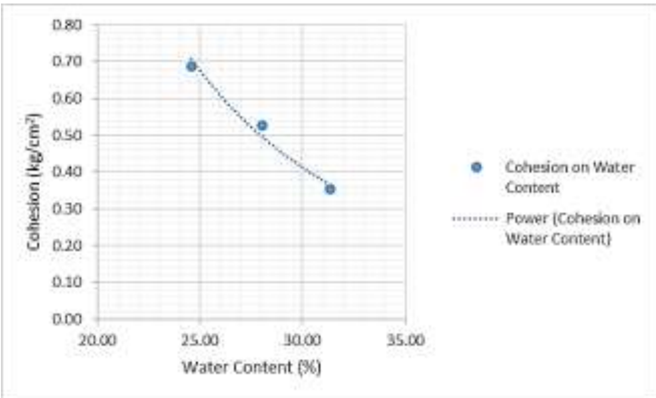

Fig. 7. Cohesion on water content by triaxial testing.

Fig. 6 demonstrates that the greater the water contents in the soil, the smaller the shear angle value will be. This was due to the decrease in the shear strength between particles resulted in an increase in water in the soil pore giving the lubrication effect. This also proves the clay shale soil properties that was highly vulnerable to water, so that it could

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decrease the soil shear strength along with the increase in the water content. This was also in line with the cohesion value shown in Fig. 7, the greater the water content, the smaller the cohesion value will be. The water in the soil pores also increased, so the bonds between particles in the soil weakened. From this result, it could be concluded that the shear strength of the clay shale soil would decrease along with the amount of the water content in the soil.

C. Soil Water Characteristics Curve (SWCC)

Soil-Water Characteristic Curve (SWCC) is used to determine the suction power of unsaturated soil. SWCC test results are shown in Fig. 8. At a water content of 40.75% the ability of soil to absorb water (suction) can reach 56.67 kPa, while for water content 46.17% the ability of soil to absorb water (suction) is 27.53 kPa. The lower the water content in the soil so the ability of the soil to absorb water will be higher, this is because soil samples with low moisture content have more pores.

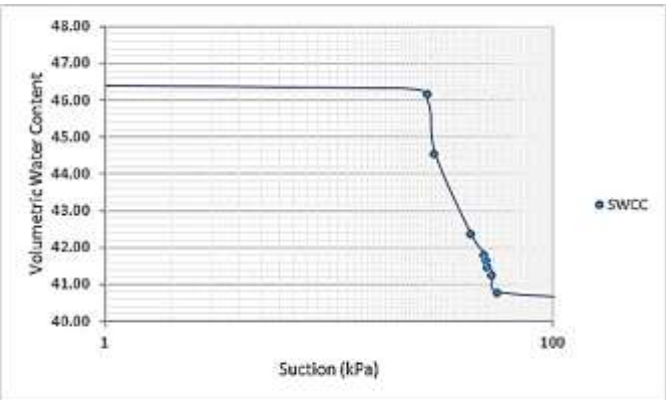

Fig. 8. Soil water characteristics curve of clay shale.

D. Safety of Factor Analysis

In this research, SF analyzed in two conditions, the first condition analyzed without rainwater infiltration, and the second condition analyzed with rainwater infiltration. The data that used in the analysis are topography data, rainfall data, and soil parameter data.

TABLE II. SEEP/W parameter data.

Layer	*Parameter*				
	WC (%)	Pass filter size		LL (%)	k (cm/det)
		>10%	>60%		
1	23.17	0.002	0.075	26.3	$1x10^{-5}$
2	36.54	0.001	0.075	28	$1x10^{-5}$
3	27.51	0.0015	0.05	49.1	$1x10^{-5}$
4	23.17	0.002	0.075	26.3	$1x10^{-5}$

TABLE III. SLOPE/W parameter data.

Layer	*Parameter*		
	γ	c	ϕ
	gr/cm^3	kg/cm^2	°
1	1.76	0.152	22
2	1.73	0.126	18
3	1.87	0.527	4.73
4	1.76	0.152	22

The highest average rainfall is 25 mm / day for 15 rainy days. While the soil parameter data is shown in TABLE II and TABLE III, with the gradient of the layer based on the geological map is 30^o.

The SF for first condition analyzed by SLOPE/W, the slip line and pore-water pressures are shown in Fig. 9, the pore water pressure above the groundwater line is negatif. By comparing the total resisting force and total activating force that is 1758.3 kN/1315 kN, obtained SF result is 1.337. The result of SF under the second condition > 1, which means the condition of the slope in stable condition.

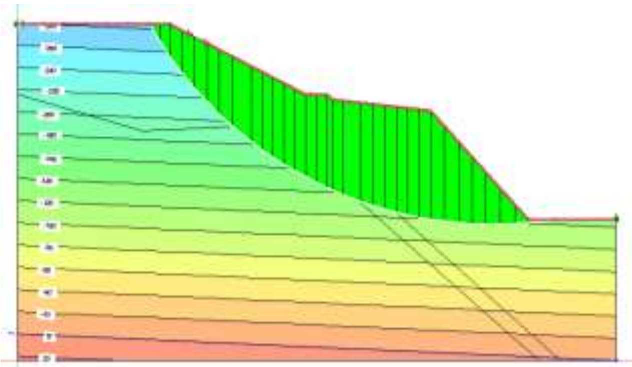

Fig. 9. Slip line and pore water pressure for firts condition analysis.

TABLE IV. Total force and moment of analysis result.

	Without Rainwater Infiltration	With Rainwater Infiltration
Method	Morgenstren-Price	Morgenstren-Price
Safety of Factor	1.337	0.907
Total volume	233.9 m^3	264.91 m^3
Total weight	4019.9 kN	4556.1 kN
Total resisting momen	72721 kN·m	55465 kN·m
Total activating momen	54384 kN·m	61152 kN·m
Total resisting force	1758.3 kN	1331.7 kN
Total activating force	1315 kN	1468.3 kN

The second condition analyzed by SEEP / W and SLOPE/W, the slip line and pore-water pressures are shown in Fig. 10, the pore water pressure at all layers is positive due to rainwater infiltration. By comparing the total resisting force and total activating force that is 1331.7 kN/1468.3 kN, obtained SF result is 0.907. The result of SF under the second condition < 1, which means the condition of the slope in an unstable state.

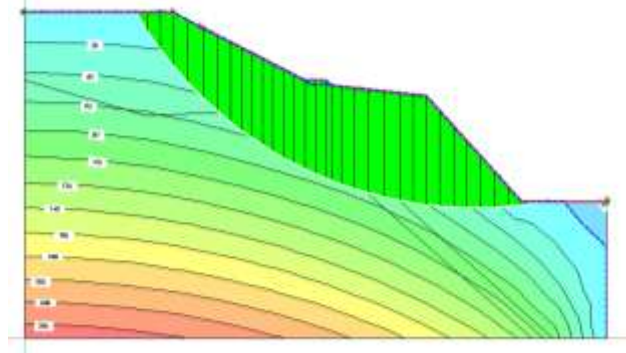

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Fig. 10. Slip line line and pore water pressure for second condition analysis.

From the results of both conditions it can be concluded that rainwater infiltration can reduce the SF value, this is because the water content in the soil increases so the soil becomes saturated and increases the pore water pressure. High water content in the soil can also decrease the shear strength of the soil.

E. Soil Improvement

Application of Stabilization with the addition of lime additives on clay soil on embankment has been done by Sutikno and Damianto in 2009, lime concentration research is 3%, 6%, 9%, and 12%, the optimum level obtained from the research is 12%. With 12% additives added the shear angle value increased 60% and cohesion increased by 165%. So in this improvement analysis will be increased the soil parameters in the embankment layer, shear angle value to 35.2^o and cohesion value 0.331 kg /cm^2.

SF analyzed in two conditions, the first condition analyzed without rainwater infiltration, and the second condition analyzed with rainwater infiltration. The result of SF analysis obtained at first condition is 1,513, and SF in second condition is 1,283, with total force and moment shown in **Error! Reference source not found.** The value of SF from the analysis of both conditions > 1, which means the condition of the slope in a stable state.

TABLE V. Total force and moment of analysis result for stabilization embankment with lime 12%.

Embankment with addition of lime additives 12%	Without Rainwater Infiltration	With Rainwater Infiltration
Method	Morgenstren-Price	Morgenstren-Price
Safety of Factor	1.513	1.283
Total volume	197.83 m^3	312.92 m^3
Total weight	3395.9 kN	5381.7 kN
Total resisting momen	69193 kN·m	68046 kN·m
Total activating momen	45742 kN·m	53043 kN·m
Total resisting force	1657.1 kN	1926.5 kN
Total activating force	1095.4 kN	1501.9 kN

V. Conclusion

From the laboratory research and the analysis that has been done, the following conclusions are obtained

1) Water content influences to shear angle and soil cohesion values, with moisture content of 24.58%, 28.06%, and 31.34% obtained the shear angle values of each sample are 9.33^o, 4.73^o, and 3.70^o, while for the cohesion value of each sample are 0.69 kg/cm^2, 0.527 kg/cm^2, and 0.35 kg/cm^2. The larger the water content the soil shear strength will decrease.
2) Rainwater infiltration can decrease SF value, from the result of both analysis, the SF value for slope condition without rainwater infiltration is 1.337, while SF value for the condition with rainwater infiltration is 0.907.
3) Chemical stabilization became one of the recommendations of soil improvement, 12% lime additives can increase the value of SF. The result SF value for slope condition without rainwater infiltration is 1.513, while SF value for the condition with rainwater infiltration is 1.283.

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