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Slope Stability Analysis Under Dry-Wetting Cycle Conditions (Case Study: Landslide Countermeasure of Batas Pidie/Aceh Besar - Batas Kota Sigli)

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ABSTRACT

A landslide occurred on National Road Section Bts. Pidie/Aceh Besar - Bts. Kota Sigli Sta. 0+500 during the peak of the rainy season has resulted in the disruption of traffic lanes. Soil samples were obtained from the landslide site for inclusion in the testing process. The laboratory tests encompass a range of physical and mechanical parameters and also dry-wetting procedures. The result shows that the topsoil layer consists of sandy silty clay with medium plasticity. Then, a dry-wetting cycle was conducted to simulate the dry and rainy season by introducing and reducing water content from the initial condition (wi) to saturated (wsat) and to airdried (wairdry) with 25%, 50%, 75%, and 100% interval. The results showed a decrease in unconfined compressive strength (qu) by 22.70% and negative pore water pressure (-Uw) by 53.14%. Slope stability analysis found that the slope was stable after the landslide with an FS value of 1.380 and increased to 1.410 when there was the addition of slab on pile road construction. The addition of rainfall variations for 3 and 5 hours is insignificant to the stability of the slope due to the groundwater table being too deep to affect pore water pressure.

Keyword : landslide, dry-wetting, SWCC, slope stability.

INTRODUCTION

The National Road is the lifeline of logistics access that has a huge impact on the economy of a region. A massive landslide on the National Road Section of Batas Aceh Besar/Pidie - Batas Kota Sigli Sta. 0+500 obstructed traffic flow to and from Banda Aceh city and negatively impacted economic growth, especially in Aceh Besar and Pidie districts. The landslide was U-shaped with a length of 60 meters and the depth of the affected slope was up to 20 meters, as can be seen in Figure 1.

Geographically, the landslide site is in a tropical region with the influence of two seasons, namely the rainy season and the dry season. The latest landslide occurred in the rainy season of January 2023. According to meteorological statistics from the Meteorology, Climatology and Geophysics Agency of Indonesia (BMKG), rainfall in this area concentrates from September to March. Changes in the water level cause variations in the factor of safety due to the influence of hydrostatic forces (Satria, 2018). Slope stability is closely related to groundwater level fluctuations caused by rainfall.

Earlier Geotechnical Investigation Report by the National Road Planning and Supervision Unit (P2JN) of the Province of Aceh shows that according to Soil parameter testing of samples taken in the rainy season showed the degree of saturation in the top layer of soil at a depth of 0 - 5 meters (sandy silt loam) ranged from 53.71 - 83.97%. At this degree of saturation, the in-situ saturation condition of the soil is in the two-phase zone or transition zone (Soemitro & Warnana, 2020). Soemitro and Warnana in 2020 mentioned that when it rains, the negative pore water stress due to pore water suction gradually increases and becomes a positive number. The result is a change in the volume and shear strength of the soil. Moreover, for certain soil conditions, a development process can occur when the soil is moistened. This process of volume change and shear strength can lead to slope failure and a decrease in the bearing capacity of the soil. Therefore, this phenomenon indicates that negative pore water stress plays an important role in determining the mechanical behavior of unsaturated soils.

Figure 1. Landslide on the National Road Section of Batas Aceh Besar/Pidie - Batas Kota Sigli Sta. 0+500

The dry-wetting conditions due to the alternation of rainy and dry seasons cause changes in the physical and mechanical parameters of soil. Previous studies mentioned that the dry-wetting cycle due to weather changes can affect the physical and mechanical properties of soil, which has an impact on the strength of the soil. The 1st cycle of the dry-wetting test on the initial soil showed changes in physical properties, mechanical properties, and negative pore water tension (-Uw) (Ariesnawan, 2015) (Rangkuti, 2024). Saleh, 2023 mentioned that the dry-wetting cycle caused changes in the physical and mechanical parameters of Bobonaro clay. The changes include a decrease in dry volume weight, an increase in void ratio, a decrease in unconfined compressive strength, and a decrease in negative pore water tension or suction. Jing et al, (2022) mentioned that dry-wetting results in changes in the physical and mechanical parameters of the soil that can affect the stability of unsaturated slopes. It is proved by the finite element simulation analysis that the slope stability is closely related to the dry-wetting cycle, the factor of safety drops sharply after the first dry-wetting cycle. The relationship between dry-wetting cycles and rainfall to stability was also demonstrated through research by Khan et al, (2019), where dry-wetting cycles increased the void ratio of Yazoo clay leading to a decrease in soil shear strength, this condition resulted in a decrease in the safety factor as the cycle increased.

RESEARCH METHODOLOGY

This research uses soil samples taken from landslide sites which will then be subjected to physical and mechanical testing in the laboratory. The samples taken include disturbed and undisturbed soil samples. The soil was taken at a depth of 0.5 - 1 meter from the original soil surface using a Shelby tube and then covered to maintain the water content.

The manufacture of dry-wetting test specimens is made by remolding the disturbed soil sample refer to the soil parameters of the undisturbed soil sample test results: soil parameters: dry volume weight ($\gamma\ d$), specific gravity (Gs), water content ($\omega\ c$). The test specimens were molded for the unconfined compressive strength (UCS) test sample with a diameter = 3.85 cm and height = 8.00 cm, while for the volumetric-gravimetric and suction test samples with a diameter = 3.85 cm and height = 4.00 cm. This test was carried out in stages through the reduction and addition of water weight with an interval of 25% water content. The reduction process was carried out by drying the test specimens under the sun and checking the weight periodically. The addition of water weight is done by dripping water on the test specimen under the reference to the addition of water weight at each interval.

A series of laboratory investigations were then conducted to obtain the physical and mechanical properties of the soil under initial and dry-wetting conditions. The physical and mechanical properties of the soil were obtained by performing Volumetric-gravimetric testing (ASTM D 2216-71; ASTM D 854-72), Negative pore water pressure using Whatman paper no. 42 (ASTM D5298-03), unconfined compressive strength test (ASTM D3080). Laboratory investigations at the initial condition and the dry-wetting condition were only carried out at the point of initial condition. Therefore, the comparison curves of the soil properties were analyzed based on the initial condition point of each cycle.

DATA COLLECTION

This study used soil samples taken from the work site of the Project Landslide Countermeasure Of Batas Pidie/Aceh Besar - Batas Kota Sigli on the National Road Section of Bts Pidie / Aceh Besar - Bts. Kota Sigli Sta. 0+500 (5.464130°N 95.784880°E), Pidie Regency, Aceh Province, Indonesia. Samples include disturbed soil samples and undisturbed soil samples. The soil taken is surface soil for the needs of testing the physical and mechanical properties of soil conducted in the laboratory. Physical properties testing included sieve and hydrometer analysis, volumetric-gravimetric test, and consistency test. The mechanical testing is an unconfined compressive strength test.

RESEARCH ANALYSIS

Test results of physical and mechanical properties of initial soil

The results of physical and mechanical properties testing on the initial soil conditions at the site are presented in Table 1. The results of the grain size distribution test show that the soil contains 8.39% gravel, 41.47% sand, 15.15% silt, and 34.98% clay. While the results of soil consistency testing show the value of liquid limit (LL) 48.98% and plastic limit (PL) 25.09%, thus obtaining a plasticity index PI of 23.89%.

Classification based on USCS shows that the initial soil belongs to the CL soil type, which is inorganic clay with silt content and low to medium plasticity. This is indicated by the grain fraction passing sieve No.200 = 50.14% (≥ 50%), liquid limit value LL = 48.98% (<50%) and plasticity index value PI = 23.89%. Based on the AASHTO classification, grains passing sieve No. 200 = 50.14% (passing sieve No. 200 > 35%) indicate the presence of clay-silt content, seen from the PI value = 23.89% (>11%), LL value = 48.98% (> 41%) and PL value = 25.09%% (< 30%), then the soil is included in group A-7-6, namely clay with silt content and low plasticity.

Table 1. Laboratorium Results of Initial Soil's Mechanical and Physical Characteristics

No.	Description		Initial Soil	
A.	Grain Size Distribution			
1.	Gravel		8,39	%
2.	Sand		41,47	%
3.	Silt		15,15	%
4.	Clay		34,98	%
B.	Atterberg Limit			
1.	Liquid Limit	LL	48,98	%
2.	Plastic Limit	PL	25,09	%
3.	Plasticity Index	PI	23,89	%
4.	Soil Clasification	USCS	CL	
		AASHTO	A-7-6	
D.	Physical Properties			
1.	Water content (initial)	wi	27,543	%
	Water content (saturated)	w_{sat}	44,812	%
2.	Specific Gravity	Gs	2,520	
3.	Volume Weight	g_n	1,510	gr/cc
4.	Dry Volume Weight	g_d	1,184	gr/cc
5.	Saturated Volume Weight	g_{sat}	1,714	gr/cc
6.	Degree of Saturation	Sr	61,462	%
7.	Void Ratio	e	1,129	
8.	Porosity	n	0,530	%
E.	Mechanical Properties			
1.	Unconfined Compressive Strength Test	q_u	0,462	kg/cm^2

Source: Author's data, 2025

Dry-wetting Tests

This test was carried out in stages through the reduction and addition of water weight at intervals of 25% water content. The reduction process is carried out by drying the test specimens in the sun and checking the weight periodically. The drying process for the initial soil starts from the initial water content condition (wn) to the dry water content under air dry condition (wairdry). While wetting process was conducted by adding water to the soil samples by dripping water following the reference for the addition of water weight at each interval. It starts from the W-100% soil airdried water content condition (wairdry) to the w+100% soil water condition (wsat).

Analysis of Soil Parameter Relationships Due to Dry-Wetting Tests

1. Effect of the dry-wetting cycle on the physical properties

   The dry-wetting process will affect the physical and mechanical properties of the soil. Figure 2 shows the graphs of the relationship between the physical property parameters of the sample soil, among others: relationship between water content (w) and void ratio (e), relationship between negative pore water pressure (-Uw) and void ratio (e), relationship between water content (wc) and degree of saturation (Sr), relationship between negative pore water pressure (-Uw) and degree of saturation (Sr), relationship between water content (W) and negative pore water pressure (-Uw), relationship between water content (w) and dry volume weight ($\gamma\ d$).

Figure 2(A) shows the graph of the relationship between water content and dry volume weight of soil. It can be seen that the application of dry-wetting from cycle 1 to cycle 2 causes a decrease in soil dry volume weight (γd) as the water content (w) increases and conversely increases when the water content decreases. As seen in the initial condition with a water content (w) of 26.872% has a soil dry volume weight (γd) of 1.231 gr/cc, after the drying process until the air dry condition with a water content of 2.125% resulted in an increase in soil dry volume weight (γd) to 1.351 gr/cc otherwise as the water content increases, (w) the behavior of soil dry volume weight (γd) value decreases. When compared to the initial soil dry volume weight (γd) value, at the 1st drying there was an increase of 9.82%, but at the 2nd drying there was only an increase of 6.784%. At the 1st wetting, there was a decrease in soil dry volume weight (γd) of 5.414% and at the 2nd wetting of 4.839%. This shows that as the dry-wetting cycle goes on, the change in soil dry volume weight (γd) will be smaller.

Figure 2(B) shows the graph of the relationship between water content and degree of saturation. The application of dry-wetting from the 1st cycle to the 2nd cycle causes an increase in the degree of saturation (Sr) as the water content (w) increases and conversely decreases when the water content decreases. As seen in the initial condition with a water content (w) of 26.872% has a degree of saturation (Sr) of 64.609%, after the drying process until the air dry condition with a water content of 2.125% resulted in a decrease in the degree of saturation (Sr) to 6.148% otherwise as the increase in water content, (w) the behavior of the degree of saturation (Sr) value increases. It can be seen in the graph that there is no significant difference in the behavior of the degree of saturation (Sr) between the 1st cycle and the 2nd cycle, where in the drying condition the change only occurs by 3.394%, while in the wetting condition by 0.952%. This indicates that the application of dry-wetting cycles on the tested soil does not have a significant impact.

Figure 2(C) shows the relationship graph between water content and void ratio. It can be seen that the application of dry-wetting from the 1st cycle to the 2nd cycle causes a decrease in the void ratio (e) as the water content (w) decreases and conversely increases when the water content increases. As seen in the initial condition with a water content (w) of 26.872% has a void ratio (e) of 1.049, after the drying process until the air dry condition with the water content of 2.125% resulted in a decrease in the void ratio (e) to 0.865, otherwise as the water content increases, (w) the behavior of the void ratio (e) value increases, this also applies to the 2nd cycle. When compared to the initial void ratio, in the 1st drying process, there is a change of 17.488% but in the 2nd drying, the change that occurs is 12.47%., while in the first wetting process, the change was 11.155% and the second wetting was 9.844%. This condition shows that the change in the void ratio is getting smaller as the dry-wetting cycle increases. The graph also shows that there is a significant difference in the behavior of the void ratio (e) between the 1st cycle and the 2nd cycle, where in the drying condition the change occurs by 28.702%%, while in the wetting condition by 11.751%. This indicates that the application of dry-wetting cycles to the tested soil has a significant effect on the change in void ratio.

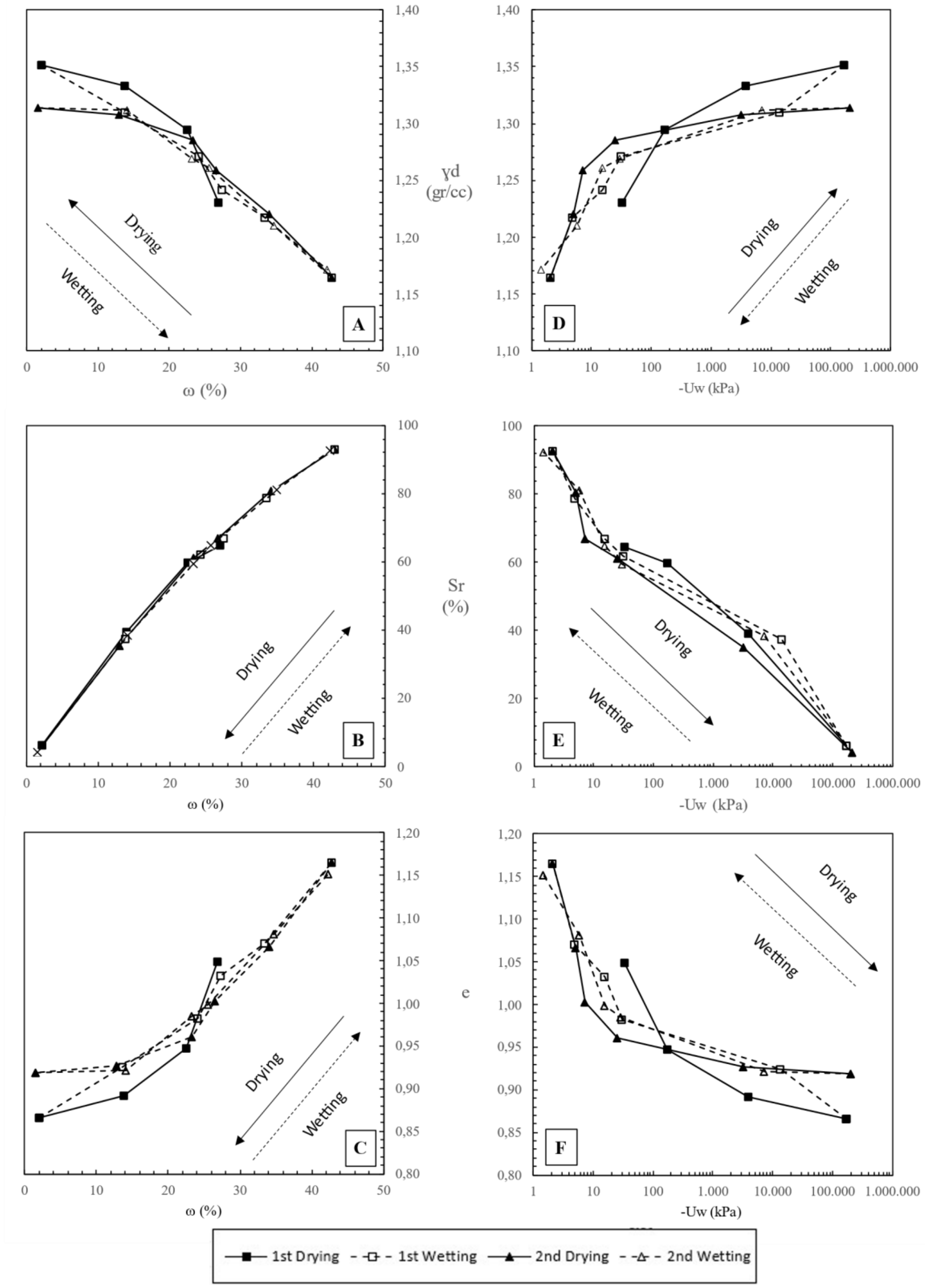

Figure 2. Effect of Dry-Wetting Cycle on Physical Properties. (A) Relationship between Water Content and Dry Volume Weight of Soil, (B) Relationship between Water Content and Degree of Saturation, (C) Relationship between Water Content and Void ratio, (D) Relationship between Negative Pore Water pressure and Dry Volume Weight of Soil, and (E) Relationship between Negative Pore Water Pressure and Degree of Saturation (F) Relationship between Negative Pore Water and Void Ratio.

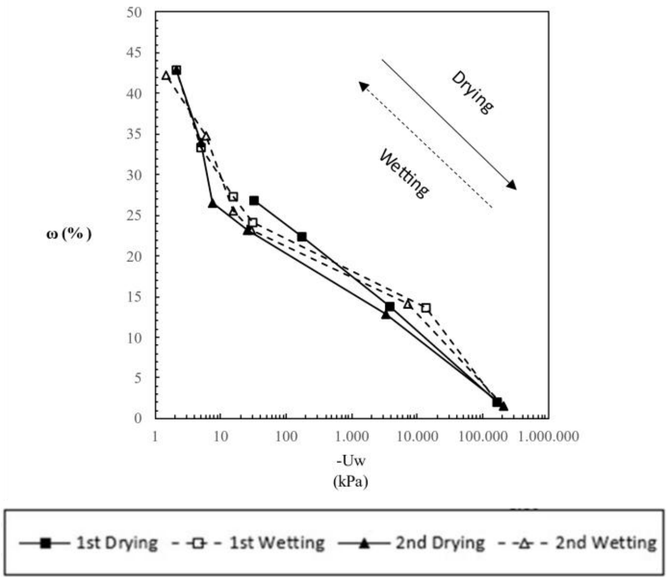

Figure 3. Effect of wet-drying cycles on physical properties, relationship between negative pore water pressure and water content

Figure 2(D) shows the relationship graph between negative pore water tension and soil dry volume weight. In general, it shows that the application of dry-wetting causes a decrease in soil dry volume weight (γd) as the negative pore-water tension (-Uw) decreases and increases as the negative pore-water tension (-Uw) increases. However, this effect decreases when the value of negative pore water tension (-Uw) starts to pass the initial value limit, where there is a sharp increase in soil dry volume weight (γd) when the value of negative pore water tension (-Uw) is still small, but the increase decreases when the value of negative pore water tension is large. It can also be seen that at the end of the drying process, there is a decrease in the soil dry volume weight (γd) value in 2nd cycle compared to 1st cycle relative to the negative pore-water tension (-Uw). While at the end of the wetting process, this change is not very significant. This indicates a significant effect of negative pore water tension (-Uw) on soil dry volume weight (γd) during drying, but little effect during wetting.

Figure 2(E) shows the relationship graph between negative pore water stress and degree of saturation. In general, it shows that in the application of dry-wetting, the negative pore-water tension (-Uw) increases with the decrease of degree of saturation (Sr) and decreases with the increase of degree of saturation (Sr). At the end of the dry-wetting process, there is no significant change between the negative pore water stress values relative to the degree of saturation values.

Figure 2(F) shows the graph of the relationship between negative pore water stress (-Uw) and void ratio (e). The graph shows that decreasing the void ratio will increase the negative pore water stress value. Conversely, an increase in the void ratio will decrease the negative pore water stress value. It can also be seen that in the early drying or late wetting phase, a large change in void ratio only has a small impact on the change in negative pore water stress value, but in the late drying or early wetting phase, a change in void ratio has a large impact on the change in negative pore water stress value. This shows that the value of negative pore water stress will be greater under the condition of a small void ratio.

Figure 3 shows the graph of the relationship between negative pore water pressure (-Uw) and water content (w). The graph shows that a decrease in water content will increase the negative pore water pressure value. Likewise, an increase in water content will decrease the negative pore water pressure value. It can also be seen that in the early drying or late wetting phase, a decrease in water content has little impact on the increase in negative pore water pressure value, but in the late drying or early wetting phase, a change in water content value has a large impact on the negative pore water pressure value. This shows that the value of negative pore water pressure will be greater under the condition of slight water content.

2. Effect of the dry-wetting cycle on mechanical properties

Figure 4(A) shows the graph of the relationship between water content (w) and unconfined compressive strength (qu). In general, it shows that an increase in water content will cause a decrease in the unconfined compressive strength value, and vice versa. In the initial condition with a water content of 26.872%, the unconfined compressive strength value is 0.158 kg/cm2, after drying with a water content of 2.215% the unconfined compressive strength value becomes 1.846 kg/cm2. However, after wetting with a water content of 42.869%, the unconfined compressive strength value decreased to 0.006 kg/cm2. The dry-wetting cycle also caused a decrease in the unconfined compressive strength value of the test soil. This can be seen in the changes in the unconfined compressive strength values of cycles 1 and 2 which decreased by 22.70%.

Figure 4(B) shows the graph of the relationship between dry volume weight and unconfined compressive strength. It generally shows that an increase in the dry volume weight of the soil will lead to an increase in the unconfined compressive strength value, and vice versa. In the initial condition with soil dry volume weight of 1.231 gr/cm3, the unconfined compressive strength value is 0.158 kg/cm2, after drying to air dry with soil dry volume weight of 1.351 gr/cm3, the unconfined compressive strength value increases to 1.846 kg/cm2. The opposite occurs when wetting where at a dry volume weight of 1.164 gr/cm3, the unconfined compressive strength value decreases to 0.006 kg/cm2.

Figure 4(C) shows the relationship between void ratio and unconfined compressive strength. In general, it shows that an increase in the void ratio will cause a decrease in the unconfined compressive strength value, and vice versa. In the initial condition with a void ratio of 1.049, the unconfined compressive strength value is 0.158 kg/cm2, after drying to air dry with a void ratio of 0.865 the unconfined compressive strength value increases to 1.846 kg/cm2. The opposite occurs when wetting where the void ratio is 1.166, the unconfined compressive strength value decreases to 0.006 kg/cm2. However, the dry-wetting cycle on the test soil in addition to causing a decrease in void ratio is also followed by a decrease in unconfined compressive strength, from cycles 1 and 2 with a decrease in void ratio of 4.43% followed by a decrease in unconfined compressive strength value of 22.70%.

Previous studies have also shown results with the same soil behavior that there is an effect of dry-wetting application on changes in soil parameters. Some of these studies can be seen as follows:

Research conducted by Rizka Adi Ariesnawan, 2015, with the research title: Mechanical and Dynamic Characteristics of Clay Shale Tuban Regency Against Changes in Water Content. It shows that the dry-wetting cycle affects the physical property parameters of Tuban clay shale. The dry-wetting cycle results in structural changes or changes in the pore space of clay shale that expands and shrinks, thus affecting the void ratio (e) and density. A significant increase in void ratio (e) occurred when the clay shale experienced wetting once (1 cycle), which amounted to 13.75%. At the end of the 2nd cycle, the void ratio (e) of Tuban clay shale increased by 15.47%

from the initial condition and the dry-wetting cycle caused the mechanical parameters of Tuban clay shale to decrease. From the initial condition to the end of cycle 2, the compressive strength (qu) of clay shale decreased by 70.41%. Changes in water content affect the compressive strength (qu) of clay shale. From dry to saturated condition, the range of compressive strength (qu) changes by 25.8 times, from 44.773 kg/cm2 to only 1.66 kg/cm2.

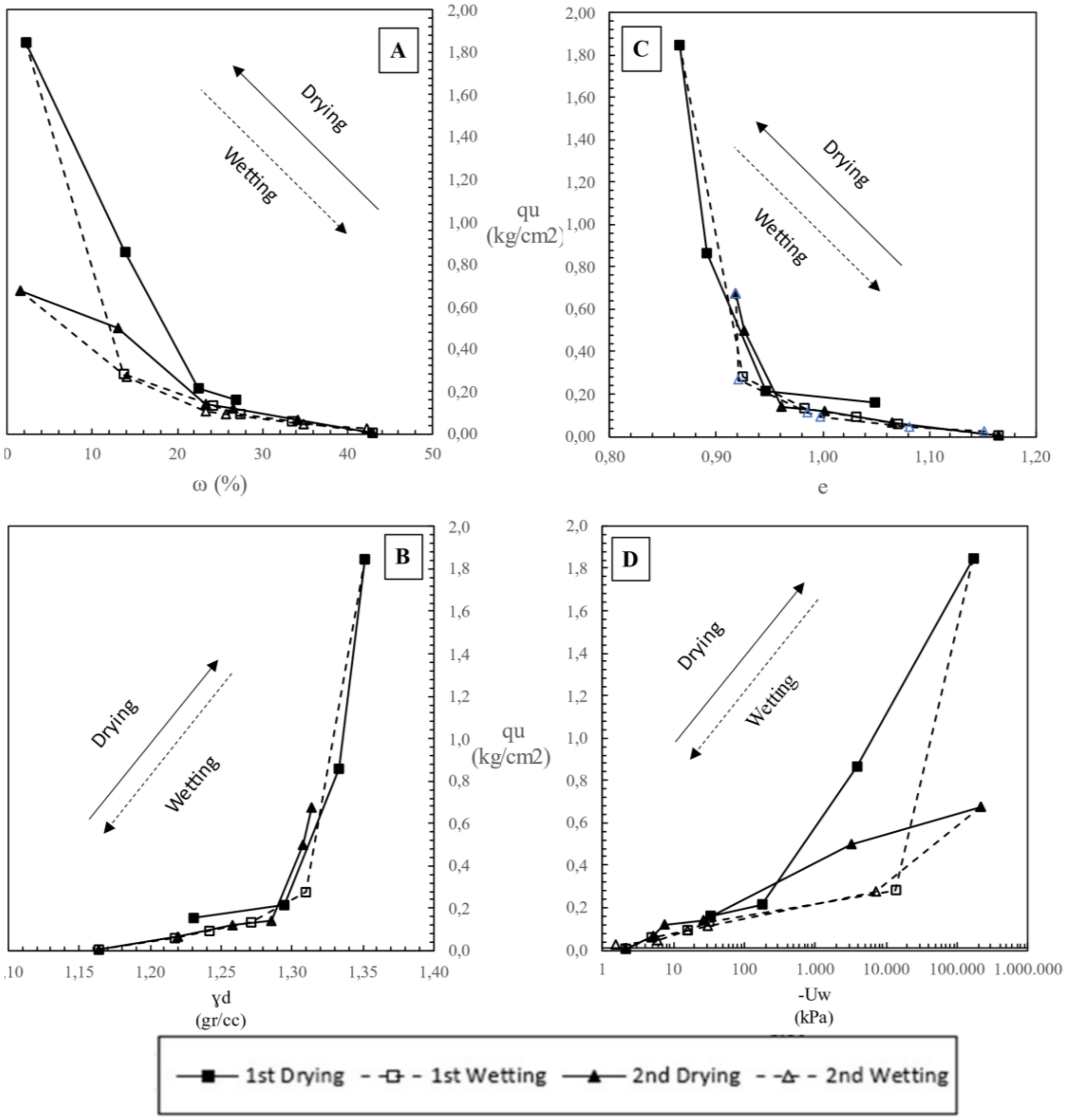

Figure 4. Effect of dry-wetting cycles on mechanical properties, (A) Relationship between water content and unconfined compressive strength, (B) Relationship between dry volume weight and unconfined compressive strength, (C) relationship between void ratio and unconfined compressive strength, (D) relationship between negative pore water tension and unconfined compressive strength

Muntaha et al, 2016, with the research title: Physical and Mechanical Characteristics of North Balikpapan Residual Soil Under the Effect of Water Content Variation. The test results of soil samples at three different locations show a considerable variation of physical and mechanical properties changes during the dry-wetting process. At a depth of 0.5 m ITK residual soil, during wetting experienced a decrease in cohesion of 30.24%, and the void ratio increased by 42.25%; PLTU residual soil experienced a decrease in soil cohesion of 15.29%, and the void ratio increased by

35.38%; PJI residual soil experienced a decrease in soil cohesion of 31.59%, and the void ratio increased by 31.79%. During the drying process from the initial condition to the 100% drying condition, ITK residual soil experienced an increase in soil cohesion of 34.09%, and void ratio decreased by 55.30%; PLTU residual soil experienced an increase in soil cohesion of 26.01%, and void ratio decreased by 53.40%; and PJI residual soil experienced an increase in soil cohesion of 29.14%, and void ratio decreased by 53.87%.

Dry-wetting research was also conducted by Trihanyndio Rendy Satrya, Ria Asih Aryani Soemitro, Toshifumi Mukunoki and Indarto, 2017, with the title of the study: Wetting and Drying: Change of Soil Properties in the Bengawan Solo River Embankment due to Drying-Wetting Cycles. The results showed that due to wetting in cycle 1 of dry-wetting, the dry unit weight of soil decreased by about 22.49%, from 15.56 kN/m3 to 12.06 kN/m3. Similarly, the soil dry weight decreased gradually by 21.48%, from 14.62 kN/m3 to 11.48 kN/m3 in the 2nd cycle wetting process. However, it was slightly lower in reduction rate than in cycle I. In the 3rd cycle, the dry unit weight of the soil decreased gradually by about 17.36%, from 14.46 kN/m3 to 11.95 kN/m3. This means that the reduction rate was lower than in cycle II.

Muh. Saleh conducted research in 2023 with the title Analysis of Slope Stability in View of Dry-wetting Aspects and Rainwater Infiltration of Bobonaro Typical Clay Soil, showing the results of the application of the dry-wetting cycle caused a decrease in the physical parameters of Bobonaro clay caused by changes in soil structure or affecting soil pore space so that changes in density and void ratio occurred. The decrease in dry volume weight (γd) was 4.043% while there was an increase in void ratio (e) of 13.82% from cycle 1 to cycle 3 and relatively stable from cycle 2 to cycle 3. The dry-wetting cycle also caused a decrease in the mechanical parameters of Bobonaro loam in the form of a decrease in unconfined compressive strength (qu) of 21.51%. Changes in water content weaken the bond between soil grains, thus reducing the strength index of Bobonaro clay from the category of stiff clay to medium clay.

Research by Rahmadsyah Rangkuti, 2024 titled Stabilization of Soil with Lime Ca(OH)2 to Improve the Physical and Mechanical Properties of Soil as Backfill Material (Case Study: Trengguli Road Section - Bts. Kab. Kab. Demak/Kudus), showed that after one dry-wetting cycles on the initial soil, there were changes in physical and mechanical properties, also in negative pore water tension (-Uw). The result shows a decrease in dry volume weight value (γd) by 8.456%, an unconfined compressive strength value (qu) decreased by 93.004% (from medium to very soft consistency), and an increase in void ratio value (e) by 17.082%.

Soil Water Characteristic Curve (SWCC)

SWCC is a relationship curve between the value of volumetric water content, VWC (θ), and the value of negative pore water pressure or suction (-Uw). Where the VWC value is obtained from the volume of water divided by the total volume (Vw/V), while the -Uw value is obtained from the results of suction testing using the filter paper method (ASTM D 5298-03) Whatman no. 42. The results of the calculation of the volumetric water content value, VWC (θ) and negative pore water pressure (-Uw) are shown in **Figure 5**.

Based on the relationship curve between the value of Volumetric Water Content, VWC (θ) and the value of negative pore water pressure or suction (-Uw), it is found that in air-dry water content conditions (Wairdry) the lowest VWC (θ) value is 2.009% and the highest suction (-Uw) value is 207.761,806 kPa, while in saturated water content conditions (Wsat) the highest VWC (θ) value is 49.476% and the lowest suction (-Uw) value is 1.482 kPa. This result shows the general behavior in the dry-wetting process that as the VWC (θ) value decreases, the suction (-Uw) value increases, and vice versa. During the dry-wetting process, the value of VWC (θ) increases, while the value of suction (-Uw) decreases, this is because the increase in the value of VWC (θ) is directly proportional to the increase in water content value, while the increase in suction (-Uw) is inversely proportional to the increase in water content value.

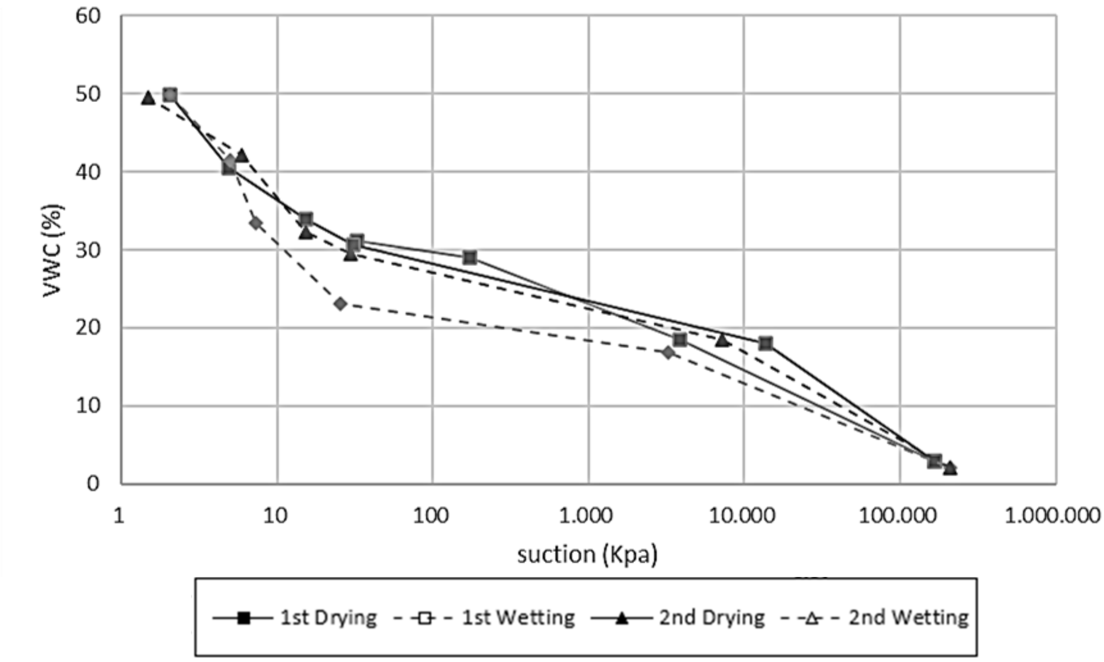

Figure 5. Comparison graph of suction value (-Uw) to Volumetric Water Content, VWC (θ)

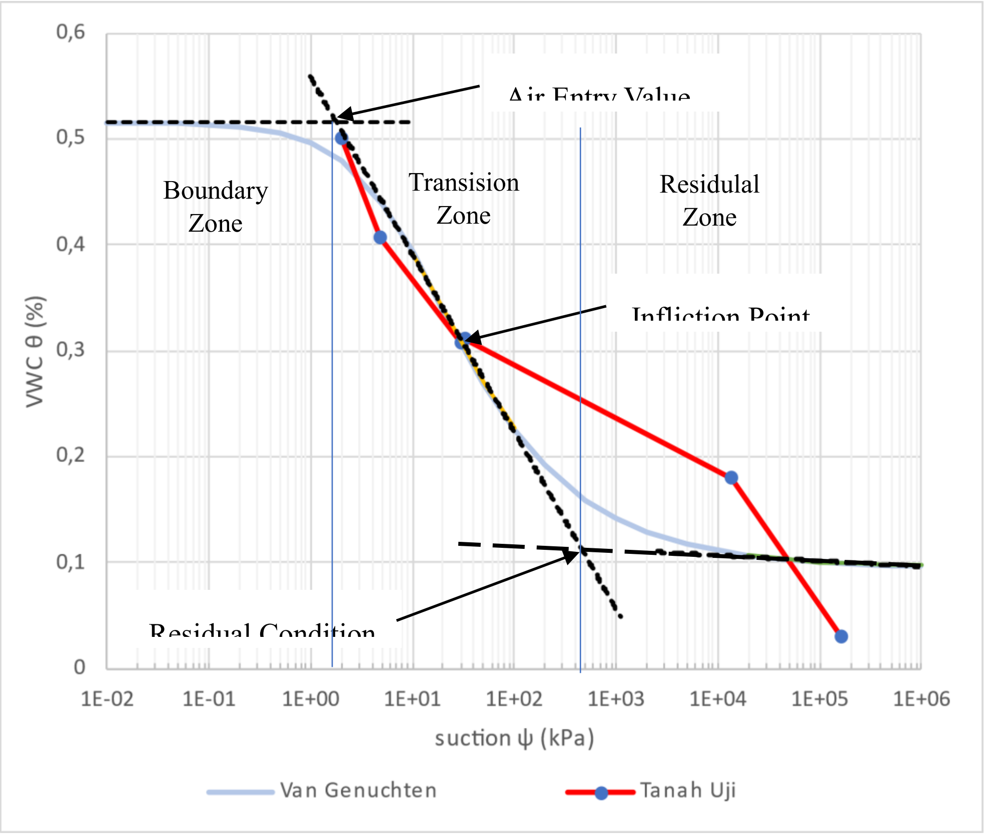

Figure 6. Fitting the SWCC Curve of the test soil with the Van Genuchten method

To obtain the SWCC curve parameters, it is necessary to fit the curve which in this case uses the Van Genuchten method as shown in **Figure 6**. The fitting results show the following unsaturated soil parameters: Saturated volumetric water content (θs) = 0.5153, Residual volumetric water content (θr) = 0.0952, Air entry value (AEV) = 1.8057 kPa, Residual condition point (Res) = 449.1803 kPa. For best fitting parameters are as follows α = 0,1105, m = 0,0099, and n = 1,0100.

Back Analysis of Landslide

The back analysis uses a soil parameter approach based on changes in soil consistency according to both Terzaghi and Peck, 1967 then analyzed using an auxiliary program. Trial and error methods were tried by adjusting soil mechanic parameters until the stability of the analyzed slope approached the safety number close to 1. As the result is SF value of 1.006 was obtained which is very close to SF ≈ 1. The soil parameters obtained shortly before the landslide were soft soil consistency with undrained cohesion (Cu) of <21 kPa, inner shear angle (ϕ) of 0°, and modulus of elasticity E' of <11.000 Mpa.

Slope Stability Analysis

The analysis was conducted by modeling the slope after the landslide to determine the stability of the exposed slope. The slope stability analysis used soil parameters in the initial condition for the top layer of soil at the landslide point with undrained cohesion (Cu) 22,653 Kpa. In the initial condition (post landslide) without the application of rain, the factor of safety SF = 1.380 was obtained. The condition shows that the slope has reached a stable stage after the landslide with a safety number above the required SF>1.25.

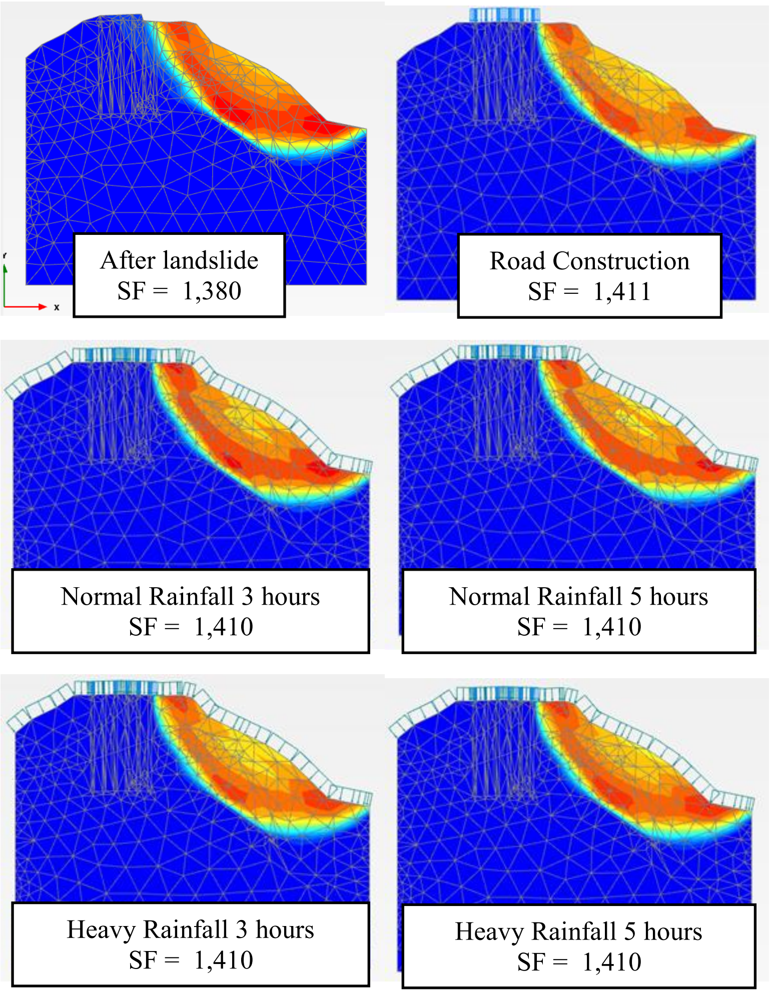

Figure 7. Slope stability analysis at initial condition with rain variation

The next stage analyzed the condition after the road construction treatment (slab-on-pile structure) and showed an increase in the safety factor value to SF = 1.410. This indicates that the slab-on-pile method helps to improve the stability of the slope. The next variation is the application of normal rain with an infiltration rate (i) of 28.7184 mm/hour or 0.6892 mm/day for 3 hours. The analysis showed that the slope had a factor of safety of SF = 1.411 while the same infiltration rate with a 5-hour duration obtained a factor of safety of SF = 1.410. The next analysis uses heavy rain variations with an infiltration rate (i) of 44.0987 mm/hour or 1.0583 mm/day for 3 hours. The analysis showed that the slope had a factor of safety of SF = 1.410, while the same infiltration rate with a duration of 5 hours also obtained a factor of safety of 1.410.

Analysis of the initial condition shows that after the landslide, the slope has stabilized. The implementation of road construction (slab on pile structure) can increase the safety number due to the effect of using bore pile construction. Meanwhile, the addition of normal and heavy rainfall has no impact on slope stability. This is because the position of the groundwater is so deep that it is not affected by rainfall, so it does not have a major impact on the decrease in shear strength due to the increase in soil pore water pressure. The factor of safety values ranging from 1.410 to 1.411 is still above the safety limit of FS > 1.25, thus the slope is still safe.

CONCLUSION

Results of data analysis of dry-wetting test with 2 (two) cycles and slope stability analysis on landslide locations Bts. Aceh Besar/Pidie - Bts. Kota Sigli STA.0+500 gave the following conclusions:

1. The dry-wetting cycle caused a decrease in soil physical parameters at the landslide site due to changes in soil structure caused a decrease in mechanical parameters as unconfined compressive strength (qu) decreased by 22.70%. The change in water content caused a change in the bond between soil grains, thus reducing the strength index of the soil at the landslide site.
2. The dry-wetting cycle test on the soil at the landslide site shows that the Soil-Water Characteristic Curve (SWCC) is formed with the maximum suction value occurring when the volumetric water content (VWC) is at a minimum value. Fitting the SWCC curve with the Van Genuchten method resulted in unsaturated soil parameters such as saturated volumetric water content (s) = 0.6969, Air entry value (AEV) = 1 kPa, Residual volumetric water content (r) = 0.0201, best fitting parameters m = -1.2372 and n = 0.4470.
3. Back analysis results showed that the estimated critical soil parameters of the surface layer just before the landslide are unconfined compressive strength (Qu) < 42 kN/m2 and cohesion (Cu) < 21 kN/m2 with the SF value of 1.006.
4. Analysis of the initial condition shows that the post-landslide slope has been stabilized. The implementation of road construction (slab on pile structure) can increase the safety number because of using bore pile construction. Meanwhile, the addition of normal and heavy rainfall for 3 and 5 hours has no impact on slope stability due to the groundwater table being too deep to affect pore water pressure.

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