Effects of water content to slope stability in Pangkalan Lima Puluh Kota

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Abstract. The objective of the study was to investigate the relationship between soil water content and steepness stability in the three locations of Pangkalan District of Lima Puluh Kota. The sample data in the form of soil is tested to obtain a plastic and liquid Boundary so that it can be investigated soil strength and its relation to the water content. The test is done by determining the sample strength parameters in the initial conditions, then the water content of the sample is modified according to the plastic and liquid boundaries, as well as the unit volume. The figures for slope stability analysis were analyzed using laboratory and cross-sectional results. Test results show that the water content is the most important factor affecting the stability of the slope. Slope stability becomes critical when the water content is close to its liquid limit. However, the water content less than the plastic limit also results in a less strong soil parameter for the sample being remolded. To reduce slope failure, it is recommended to establish water control facilities in the area.

1. Introduction

Indonesia is an area that has the potential geological disasters of the movement of land is quite high, the movement of the soil, general can occur due to slope stability is reduced due to soil degradation, ie decreasing the nature of soil engineering either by natural factors such as increased rainfall, weathering or due to human activities. West Sumatra is an area susceptible to land movement, one of which is a district of Lima Puluh Kota. Geographically the district of Lima Puluh Kota lies at 0°25'28,71''LU-0°22'14,52''LS and 100°15'44'10''BT-100°50'47'80 '' BT and has an area of 712,06 km².
The administrative district of Lima Puluh Kota is adjacent to the region as follows: Regency of Rokan Hulu in the north and Kampar regency in Riau province. The south is bordered by Tanah Datar and Sijunjung districts. Regency of Agam and Regency of Pasaman in the west. Regency of Kampar and Riau Province in the east.

Generally, the district of Lima Puluh Kota is passed by two river systems, the Kampar Kanan Watershed in the north and the Kuantan River basin in the south. Kabupaten Lima Puluh Kota is upstream of several rivers flowing into the provinces of Riau and Jambi. Both watersheds are a priority I watersheds that need immediate rehabilitation as they have a lot of critical lands.

Kabupaten Lima Puluh Kota is the easternmost district in West Sumatra province which is the main gateway on the ground with Riau province. This area consists of hills and cliffs along State Road, Pangkalan Kabupaten 50 Kota. These conditions cause the frequent occurrence of landslide events covering the road along the road segment Payakumbuh-Pangkalan, this resulted in the breaking of the path crossing West Sumatra with Riau province.

Pangkalan is a sub-district located in Lima Puluh Kota district, West Sumatera province, with the capital of Koto Baru Base The total area according to the nagari is as follows: Nagari Koto Alam (42.75km²), Nagari Manggilang (58.75km²), Nagari Pangkalan (124.3km²), Nagari Gunung Malintang (249.43km²), Nagari Tanjung Balik (124.57km²), Nagari Tanjung Pauh (112.26km²).

In April 2016 and in the base area there has been a landslide event, the disaster has suffered material losses and eliminate human life. Events of landslides, this happens due to high rainfall, which causes rainwater into the soil and causes the soil to become saturated. According to [1]. The saturated soil contains high moisture content, due to the long rain then the pore water pressure will rise, the increase of pore pressure causes the shear strength of the soil to become small and eventually the land becomes unstable and prone to landslides, based on the above conditions motivated authors to conduct research in the area The base of the district of Lima Puluh Kota.

2. Review of Literature

2.1. Slopes stability

Slope stability is a condition or state that is stable or stable to the shape and dimensions of the slope according to [2]. The slope is a surface that connects the higher ground with lower soil surface, and the stability of the slope is closely related to landslide or movement of soil which is the process of natural land mass transfer from high place to lower place [3] [4]. There are 2 (two) kinds of slopes that are natural slopes formed by nature or environment in the form of rocks, other material, soil or mixed material, and man-made slopes by cutting the cliff or the construction of the slope [5].

Impaired stability of the slope (landslide) occurs due to the displacement of slope forming material down or out of the slope, and can be controlled by morphological conditions (especially slope gradient), rock conditions/slope constituents, and hydrological or water conditions on the slopes [6].

Factors that cause instability of natural slopes are [7]:

1. Rainfall: High rainfall can cause the land to become saturated, which reduces the shear strength of the soil and makes it more prone to landslides.
2. Temperature: High temperature can cause the soil to expand and contract, which can weaken the stability of the slope.
3. Soil type: Soil types that have poor drainage or high water content are more prone to landslides.
4. Slope angle: Steep slopes are more prone to landslides than flat slopes.
5. Vegetation: The presence of vegetation on a slope can reduce the risk of landslides by stabilizing the soil and reducing erosion.
6. Geological factors: The nature of the rock or soil formation can affect the stability of the slope, with some rocks or soils being more prone to landslides than others.
7. Human activities: Activities such as excavation, construction, and land clearing can disrupt the natural stability of a slope and increase the risk of landslides.
a. Slope profile changes in slope due to additional load at the top of the slope or reduced strength at the bottom of the slope.
b. Increased groundwater pressure resulting in decreased shear resistance in non-cohesive soils or development of cohesive soils. Groundwater pressure may increase when the soil is saturated from rain, seepage, or surface water.
c. Decreased strength of soil shear or rock caused by weathering, washing, mineralogy changes, and fractures.
d. Vibrations caused by earthquakes, blasting, or pole erection

2.2. Data required for slope design

2.2.1 Topographic Data

According to [8] Slope is the appearance of a natural surface that has a high bed. If the height difference between the two places is compared with the horizontal straight distance, the slope will be obtained " The shape of the slope depends on the process of soil erosion and weathering. The slope has a topographic parameter that is divided into two parts, namely the slope of the slope and the height of the relief.

While topographical data [9] suggests that topographic maps provide an overview of the slope, height differences, river density, flow patterns, altitude, and morphological form. From the topographic map can also be interpreted the erosion level of an area. Things that can lead to slope collapse on highway cliffs, railroads, rock excavation cliffs, and cliff dams should be recorded because they are unlikely to be seen in small-scale geological maps. The combination of river density and slope of the topography map will provide better data. Generally, areas with high river density tend to have larger landslide tendencies.

2.2.2 Geological Data Engineering

When we discuss the geological data of our technique cannot be separated from talking about the land. The soil in the engineering sense is generally defined as a material consisting of aggregates (granules) of unorganized solid minerals (chemically bonded) with each other and of decayed organic materials (solid particles) accompanied by liquids and gases that fill the empty spaces between the solid particles [10]. [9] Engineering geology (scale and depth of geological studies, mapping of surface geology and geological structures, stratigraphy, and rock units); Technical geological mapping is required to determine the type and distribution of rocks and geological structures, as well as to include geological processes related to slope collapse and groundwater forecasting in the investigation area.

2.2.3 Data of soil and rock investigation for slope stability

To conduct a soil investigation of the slope there are 2 test data:

a. Field test data

Field tests conducted for slope stability investigations may be undertaken in geotechnical drilling holes or not, and may comprise one or a combination of test types on Table 1 [9].
Table 1. Field trials of slope stability

| Type of test                        | Standard of test                        |
|-------------------------------------|-----------------------------------------|
| Standard Penetration Test, (SPT)    | SNI 4153 – 2008                          |
| Cone Penetration Test (CPT)         | SNI 2827 – 2008                          |
| Vane Shear Test (VST)               | SNI 03-2487 – 1991 (ASTMD 2573/D2573M-15) |
| Borehole shear test (BST)           | ASTM STP740 (1981)                       |
| Pressuremeter Test (PMT)            | EN ISO 22476                             |
| Dilatometer Test (DMT)              | ASTM D 6635-15                           |
| Seismic Refraction Test             | ASTM D 4428/D 4428M-14                   |
| Geo-electricity                     | SNI 2528 – 2008                          |

Table 2. Field tests of slope stability investigation

| Type of test                        | Standard of test                        |
|-------------------------------------|-----------------------------------------|
| Nature of soil Index                | SNI 1966-2008                           |
|                                     | SNI 1967-2008                           |
|                                     | SNI 1976-2008                           |
|                                     | SNI 3422-2008                           |
|                                     | SNI 3423-2008                           |
| Triaxial UU / Triaxial CU and or Triaxial CD | SNI 4813-2008                           |
|                                     | SNI 2455-2008                           |
| Strong free press (UCS test )       | SNI 3638-2008                           |
| Swipe Direct                        | SNI 2813-2008                           |
| Consolidation                       | SNI 2812-2008                           |

b. Laboratory test data
In this study, the laboratory tests undertaken for slope stability investigation are the properties of soil index and direct shear test (free share) and free compressive strength (UCS Tests). Laboratory tests undertaken for ground slope stability investigation are shown in the Table 2 [9].

Table 2. Field tests of slope stability investigation

| Type of test                        | Standard of test                        |
|-------------------------------------|-----------------------------------------|
| Nature of soil Index                | SNI 1966-2008                           |
|                                     | SNI 1967-2008                           |
|                                     | SNI 1976-2008                           |
|                                     | SNI 3422-2008                           |
|                                     | SNI 3423-2008                           |
| Triaxial UU / Triaxial CU and or Triaxial CD | SNI 4813-2008                           |
|                                     | SNI 2455-2008                           |
| Strong free press (UCS test )       | SNI 3638-2008                           |
| Swipe Direct                        | SNI 2813-2008                           |
| Consolidation                       | SNI 2812-2008                           |

Consolidation tests may not be required depending on the problem.
In relation to the soil properties in the soil strength determination there are several properties that need to be known, among others:

2.3. Water content
The moisture content is a soil property that describes the ratio of the water weight present in the soil sample to the weight of the dried soil particles. Water content has a% unit. In mathematical equations the moisture content can be written as follows:

\[ W = \frac{W_{w}}{W_{s}} \times 100\% \]

(1)

where:
\( W \) = Water content
\( W_{w} \) = weight
\( W_{s} \) = The weight of the soil is dry

Testing of moisture content is very important in studying the clay properties (activity) on the influence of water, the value of the activity of clay in interacting with water is often expressed as the plasticity index (Ip) which is the difference of the water content in the conditions of its liquid limit (WLL) with the moisture content in its plastic limit state (WPL). If the fine-grained soil contains clay minerals, then the soil may be crushed without causing cracks, this cohesive nature is due to the presence of water absorbed around the clay surface. The water content is expressed in percent, where the transition from a solid state to semi-solid is called the shrinkage limit. The water content in the transition from a semi-solid state to a plastic state is called the elastic limit. And from a plastic state to a liquid is called a liquid limit. These limits are also called the Atterberg limit.

2.4. Slope design criteria
In [9] slope safety factors required for stability analysis of the slope are shown in Table 3 based on cost considerations and consequences of slope failure on the degree of uncertainty of the analysis conditions

| Costs and consequences of slope failure | The degree of uncertainty of the analysis conditions |
|----------------------------------------|-----------------------------------------------|
| The cost of repairs is proportional to the additional cost of designing a more | Low \(^a\) | Height \(^b\) |

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\(^a\) Cost of repairs is proportional to the additional cost of designing a more...
The cost of repair is greater than the additional cost of designing a more conservative slope 1,5

| conservative slope | 1,25  | 1,5 |
|--------------------|-------|-----|
| The cost of repair is greater than the additional cost of designing a more conservative slope | 1,5 | >= 2,0 |

a. The uncertainty level of the analysis condition is categorized as low if the geological conditions can be understood, uniform soil conditions, soil investigation is consistent, complete and logical to the conditions in the field.

b. The degree of uncertainty of the analysis condition is categorized high if the geological conditions are very complex, soil conditions vary, and soil investigations are inconsistent and unreliable.

In [11] thorough studies of slope collapse are:

| F     | Happen                      |
|-------|-----------------------------|
| F < ~1.07 | Collapse is common         |
| 1.07 < F ≤1.25 | The collapse never happened |
| F > 1.25       | Collapse is rare           |

1. Soil Slope Analysis
   In Soil Slope Analysis the method used is an analysis based on the concept of boundary balance and graph method. Boundary balance methods generally take into account the balance of force and moment balance with assumptions that must be made such as the shape and location of collapse, the direction, and style between the slices. Stability analysis by means of equilibrium balance can be done by several methods, among others: Slice Method, Force Equilibrium (Lowe and Karafiat, 1960 and USCE, 1970), Janbu (1968), Morgenstern and Price (1965) and Spencer (1967) [9].

2. Anticipation Unstable slopes
   Retaining wall is one of the concepts of soil reinforcement that is widely used in civil engineering work. Retaining wall is a wall that is used to hold the ground load vertically or to a certain slope. Several types of retaining wall are as follows:
   a. Gravity Walls
   b. Semi gravity Walls
   c. Cantilever Walls
d. Counterfort Walls
From the four retaining walls the author priority is Cantilever Walls because of the situation and conditions of the slope on the base of more than 12 m.
The equipment used in soil sampling is a sample tube, hammer, wooden block, hammer, crowbar, and plastic. In this study, samples were taken at each point as much as 3 pieces of sample tubes, so for the three points of the sample research sites taken totaling as many as 9 pieces of the sample tube. Soil sampling is shown in Figure 5.

![Soil sampling](image1)

**Figure 1.** Soil sampling

After sampling at 3 points of research location, the sample was taken by Andalas Padang Lab Mechanics. The test is done as follows, water content, Atterberg limit, weight volume, specific gravity, sieve analysis, direct shear and UCST. This test was conducted to obtain the soil parameters needed in this study.

### 3. Results

The final measurement results can be seen from the Table 5 as follows:

| Location            | Slope | High   |
|---------------------|-------|--------|
| Pangkalan 10 (PKL 10) | 27°   | 12.1 m |
| Pangkalan 16 (PKL 16) | 30°   | 6.3 m  |
| Pangkalan 22 (PKL 22) | 35°   | 10.6 m |

Table 5 shows the slope and altitude at the point of PKL 10 is 27° and 12.1 m, the point of PKL 16 is 30° and 6.3m, and the slope and the altitude at the point of street vendors 22 are 35° and 10.6m. The laboratory tests conducted consist of water levels, Atterberg limits (Soil Consistency Limit), volume weights, specific gravity, sieve analysis (sieve analyze), direct shear, UCST (strong free press). The final result of all testing of groundwater content can be seen from the following Figure 2.

Figure 2 shows the relationship of moisture content (in%) with the location of the PKL research point of 10 points 1,2 and 3 are 21,011, 28,857, and 27,909. Water content at the
locations of street vendors 16 dots 1, 2, and 3 are 43,483, 53,779, and 39,462. while the water content at the location of street vendors 22 dots 1, 2 and 3 is 26,272, 34.347 and 31.437.

**Figure 2.** Testing of groundwater content

Figure 3 shows the relationship of moisture content (in%) with the atterberg limit at the location of the PKL research point of 10 points 1, 2 and 3 are 21,011, 28,857, and 27,909. Water content at the locations of street vendors 16 dots 1, 2, and 3 are 43,483, 53,779, and 39,462. while the water content at the location of street vendors 22 dots 1, 2 and 3 is 26,272, 34.347 and 31.437.

**Figure 3.** Relation of water with Atterberg boundary

Value the weight of the soil volume ($\gamma$) is obtained will go the comparison between the weight of the soil by its volume. The final result of the soil weight volume test is shown in Figure 4. Comparison of volume weight with water content is shown.
Figure 4 shows comparison of volume weight values with moisture content (in%) and the location of PKL research points. 10 points: 1, 2, and 3 are 2.129, 2.101, and 2.205. At the point of location PKL 16 points: 1, 2, and 3 are 2.01, 1.768, and 2.17, while at point location PKL 22 points: 1, 2, and 3 is 2.179, 1.893 and 2.175.

The UCST testing is done on original and remoulded soil conditions. The end result of direct shear is as follows:

Table 6. UCST test results

| Location       | UCST          |
|----------------|---------------|
|                | qu (Kg/cm²)   | qu remoulded (Kg/cm²) |
| PKL 10 Point 1 | 0.601         | 0.456                |
| PKL 10 Point 2 | 0.373         | 0.25                 |
| PKL 10 Point 3 | 0.456         | 0.228                |
| PKL 16 Point 1 | 0.527         | 0.422                |
| PKL 16 Point 2 | 0.515         | 0.304                |
| PKL 16 Point 3 | 0.793         | 0.539                |
| PKL 22 Point 1 | 0.446         | 0.233                |
| PKL 22 Point 2 | 0.451         | 0.233                |
| PKL 22 Point 3 | 0.401         | 0.207                |

Direct shear testing is performed to determine the value of cohesion and the shear angle of the soil. In this test, it is done on the original soil samples and also remoulded soil samples. The end result of direct shear is as follows:
Table 7. Direct shear test results

| Location       | Direct Shear          |              |              |
|----------------|-----------------------|-------------|-------------|
|                | $c$ (Kg/cm$^2$)       | $\phi$ (0) |
| PKL 10 Point 1 | 0.126                 | 40.103      |
| PKL 10 Point 2 | 0.094                 | 36.386      |
| PKL 10 Point 3 | 0.108                 | 40.103      |
| PKL 16 Point 1 | 0.173                 | 19.336      |
| PKL 16 Point 2 | 0.126                 | 44.495      |
| PKL 16 Point 3 | 0.168                 | 50.031      |
| PKL 22 Point 1 | 0.075                 | 46.471      |
| PKL 22 Point 2 | 0.117                 | 46.471      |
| PKL 22 Point 3 | 0.136                 | 42.376      |

Figure 5. Effect of water weight with cohesion

Figure 6. Effect of water content with sliding angle
From the results of soil tests related to the weight of volume and direct shear obtained data

| Location of Base Point 10 (PKL 10) | γ₁ = 2.13 | γ₂ = 2.101 | γ₃ = 2.205 |
|-----------------------------------|-----------|------------|------------|
| c₁ = 0.13                         | c₂ = 0.094| c₃ = 0.108 |
| φ₁ = 40.1                         | φ₂ = 36.39| φ₃ = 40.103|

| Location of Base Point 16 (PKL 16) | γ₁ = 2.01 | γ₂ = 1.768 | γ₃ = 2.17 |
|-----------------------------------|-----------|------------|-----------|
| c₁ = 0.173                        | c₂ = 0.126| c₃ = 0.168 |
| φ₁ = 19.34                        | φ₂ = 44.495| φ₃ = 50.031|

| Location of Base Point 22 (PKL 22) | γ₁ = 2.179 | γ₂ = 1.893 | γ₃ = 2.175 |
|-----------------------------------|-----------|------------|-----------|
| c₁ = 0.075                        | c₂ = 0.117| c₃ = 0.136 |
| φ₁ = 46.47                        | φ₂ = 46.471| φ₃ = 42.376|

Based on the above data and related to field measurement, the slope stability analysis with the slice method (simplified bishop) and recovered by [7] are:

a. Base Point 10 (PKL 10) security factor 2.368
b. Base Point 16 (PKL 16) security factor 1.381
c. Base Point 22 (PKL 22) security factor 2.685

4. Conclusion

Land in Pangkalan area of Lima Puluh Kota Regency is dominated by clay and sand with nonorganic soil clay. Based on the value of the plasticity index, the ground type of the fifty district base district is clay and based on the Atterberg limit value, if the groundwater content is below the plastic limit value, the soil becomes not cohesive as it is dry, and if soil moisture is above the liquid limit, then the soil becomes dilute.

Result of 9 (nine) point of test location, only one point which is outside the limit of Atterberg limit is base point 16 (PKL 16 Point 2) with value 54.546% which at any time will be landslide, but another point if weather/rain change happened with a variation of water content will be possible changes in water content above 50% and will also occur sliding. Suitable moisture content was found in the area of Lima Puluh Kota base station ranging from 20% to 50%, since the soil moisture value was between the limit value of the plastic and the liquid limit. Based on the calculation of the slice stability method, the value of the slope safety factor at three locations is still safe. If there is a change in water content at the three points of the study site, there will be a change of safety of the slope. Therefore special handling is required by utilizing Geotechnical experts and other Civil Engineers through cooperation between local government and competent universities such as UNAND Padang, to anticipate disaster to the slopes, using cantilevered walls according to safety factor against bolsters, style shear and to the carrying capacity of the soil.
5. Suggestion

1. Because fifty counties are disaster-prone cities, the authors suggest needing to deal with problems by utilizing geotechnical experts and supported by other civil engineering experts, through cooperation between local governments and competent universities so that problems can be managed and solved in accordance with expectations.

2. This research can then be carried out by developing sensor technology that can detect soil water content on the hillside and is implemented using mobile technology applications.

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