The modelling influence of water content to mechanical parameter of soil in analysis of slope stability

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Abstract. One of the parameters in slope stability analysis is the shear strength of the soil. Changes in soil shear strength characteristics lead to a decrease in safety factors on the slopes. This study aims to see the effect of increased moisture content on soil mechanical parameters. The case study study was conducted on the slopes of Sitinjau Lauik Kota Padang. The research method was done by laboratory analysis and simple linear regression analysis and multiple. Based on the test soil results show that the increase in soil water content causes a decrease in cohesion values and internal shear angle. The relationship of moisture content to cohesion is described in equation Y = 55.713 - 0.6X with $R^2 = 0.842$. While the relationship of water content to shear angle in soil is described in the equation $Y = 38.878 - 0.258X$ with $R^2 = 0.915$. From several simulations of soil water level improvement, calculation of safety factor (SF) of slope. The calculation results show that the increase of groundwater content is very significant affect the safety factor (SF) slope. SF slope values are in safe condition when moisture content is 50% and when it reaches maximum water content 73.74% slope safety factor value potentially for landslide.

1. Introduction

Landslide is one of the natural disasters that often occur in Indonesia including the city of Padang. Padang city is part of the Bukit Barisan mountain range area which geologically has the potential movement of land (landslide). An avalanche is a movement of slope constituents (soil, rocks, or rocks) that descend the slopes due to the disruption of the material stability of the slope [6]. According to Karyono [7] in general, the stability of the slope is controlled by several factors such as geometry, geological conditions (physical properties of slope constituents and geological structures), hydrogeological conditions, and engineering properties of slope constituents.

There are several areas prone to landslides in the city of Padang one of which is the slope along Sitinjau Lauik road. Disaster monitoring data mentions the number of avalanches during 2017 are as many as seven events, of which two of them impact the crisis. Avalanches often occur especially when high rainfall during the rainy season. High rainfall and long lasting play a role in triggering the movement of the land (landslide). Rainwater that seeps into the slopes can increase the saturation of the soil on the slopes, so the water pressure to stretch the soil bonds increases as well, and finally the ground mass is transported by the flow of water in the slope. Increased moisture content leads to a decrease in the value of mechanical properties (cohesion and internal shear angle) which affects the decrease in slope stability [5].

The objective of this research is to know the relationship of soil moisture content to mechanical properties (cohesion and internal shear angle) on the slope of Sitinjau Lauik road. Each value of mechanical properties simulated the value of Safety Factor (SF) so as to get correlation of water content to SF slope. Further data will be processed using multiple linear regression analysis to obtain the relationship between slope geometry (height and slope), water content, and SF grade of slope.
outcome of this analysis will be obtained a safe slope design recommendation along the road of Sitinjau Lauik Kota Padang.

2. Theory

2.1 Water Content
The existence of water, especially groundwater (ground water) greatly affect the stability of a slope. Ground water has a pore water pressure which can lead to uplift force, thus lowering the shear strength and causing a landslide slope. Groundwater may affect the steepness of the slope in the following manner [7]:
a. Reduces rock or ground strength.
b. Changing mineral elements in rocks through chemical reactions and dissolution.
c. Change the density of rocks or soil.
d. Causes erosion.

The presence of ground water on the slope body will be a problem for the stability of the slope. This condition cannot be separated from outside influences, ie climate (represented by rainfall) that can increase ground water level, degree of saturation, or groundwater rise. The presence of water will decrease the physical properties and mechanical properties of the soil. The rising groundwater level increases the pore water pressure, which means it decreases the shear resistance of the slope masses, especially on soil material.

2.2 Parameter Mechanical Properties

2.2.1. Cohesion (c)
Cohesion is the tensile strength between the grains of soil expressed in units of weight per unit area. The greater the cohesion value the shear strength will be greater so that the slope will be more stable or safe [3].

The method of dealing with unstable slopes depends mainly on the nature of the soil encountered. The soil types and types of harmful soil formations above are layers composed of loose schist or soft clay in the form of fragments, cracked rigid clays, clays containing sand or silt, and cohesive soil masses containing layers or bags silt-tanned sands or sand [8].

2.2.2 Slide Angle (ϕ)
The inner sliding angle is an angle formed from the normal stress and shear stress relationships in the rock material. The inner sliding angle is the fracture angle formed when a rock is subjected to a voltage exceeding its shear stress. The larger the shear angle in a material, the material will be more resilient to accept the outside stress imposed so that the slope will be more stable or safe [2].

2.3 Safety Factor (SF)
The slope generally occurs through a particular plane called the slip surface. The stability of the slope depends on the driving force and the holding force acting on the slip. The resisting force is the force that holds out to avoid sliding, whereas the driving force is the force that causes the looms. The comparison between retaining forces against forces that move the soil is called the Safety Factor [2].

Thus, a minimum SF value with a certain value is recommended as the lowest FS boundary which is still safe so that the slope can be declared stable or not. In this study, the minimum safety factor used is SF ≥ (equal to or greater) of 1.25, in accordance with the procedures of Joseph E. Bowles [1], provided that:

SF ≥ 1.25: Safe Slope
SF <1.07: Unsafe Slope
SF> 1.07; <1.25: The Critical Slope

2.4 Simple and Multiple Linear Regression

Regression analysis is used to provide an explanation of the relationship between two types of variables, namely the dependent variable with the independent variable. The analysis of the relationship between two variables is called a simple regression analysis if it involves only one independent variable. The relationship between the dependent variable (Y) with the independent variable (X) is written in a general linear model on the next sheet.

$$y = i + xi$$

With \(i = 1, 2, \ldots, n\) is the regression coefficient which means the magnitude of the change in, if \(Xi\) increases one unit and the other variable is constant or called intercept. Multiple linear regression is almost the same as simple linear regression, only in multiple linear regression of independent variables more than one independent variable. The purpose of multiple linear regression analysis is to measure the intensity of the relationship between two or more variables and make predictions of the estimated values of x and y (Hastono, 2006). In general, multiple linear regression model as follows:

$$A = b_o + b_1.x_1 + b_2.x_2 + \ldots + b_k.x_k$$

\(i = 1, 2, \ldots, n\)

\(k = independent\ variable, ie\ x_1 \ldots x_k\)

From the regression equation obtained is known the interpretation of the relationship between the dependent variable with the independent through the value of the coefficient of determination \((R^2)\). The greater the value of \(R^2\), the stronger the relationship between the variables [4]. Interpretation of \(R^2\) values can be seen in Table 1.

| \(R^2\) | Interpretation   |
|--------|-----------------|
| 0.00 – 0.25 | Low Correlation |
| 0.26 – 0.50 | Fair Correlation |
| 0.51 – 0.75 | High Correlation |
| 0.76 – 1.00 | Very High Correlation |

3. Research Sites

The research sites are located on the slopes along Sitinjau Lauik Street in Padang City, with five points of data collection and laboratory testing sample (SL 1 until SL 5). The sampling map at the study site can be seen in Figure 1 (via Google earth).

![Figure 1. Sampling location map](image-url)
Slope parameter data taken include the sampling coordinates (x, y, z), altitude, and slope. Sampling using a drill hand with an average depth of 0.9 to 1 meters. Slope parameter data in the study area can be seen in Table 2.

Table 2. Coordinate and geometry of laboratory test sampling slope

| No | Coordinate (UTM) | Angle of Slope (°) | Height (meters) |
|----|------------------|--------------------|----------------|
| 1  | East = 0666877    | 51                 | 23             |
|    | South = 9894886   |                    |                |
|    | Elevation = 353 m |                    |                |
| 2  | East = 0667033    | 54                 | 14             |
|    | South = 9894960   |                    |                |
|    | Elevation = 390 m |                    |                |
| 3  | East = 0667215    | 60                 | 11             |
|    | South = 9895055   |                    |                |
|    | Elevation = 400 m |                    |                |
| 4  | East = 0666807    | 43                 | 20             |
|    | South = 9894884   |                    |                |
|    | Elevation = 405 m |                    |                |
| 5  | East = 0667937    | 65                 | 15             |
|    | South = 9894866   |                    |                |
|    | Elevation = 385 m |                    |                |

it condition of one of the slopes of data collection and laboratory sample (SL2) can be seen in Figure 2. In Figure 2, the slopes have experienced landslide indicated by the decrease of soil material from the initial position. The type of soil material is brownish-brown clay with morphology at the top and sides of the slopes overgrown by trees and nail plants. The dimension of avalanche is 7.5 meters. In addition to the foot of the slope there are several points of water seepage.

Figure 2. Sampling location (SL 2)
4. Laboratory Test Result

Laboratory tests include the physical and mechanical properties of the slope samples. Physical properties tested were weight of content, specific gravity, and moisture content of soil samples. From the test results obtained the average value of each parameter as in Table 3.

| Table 3. Physical properties testing results          | Value  | Unit  |
|------------------------------------------------------|--------|-------|
| No          | Physical Parameters          |        |
| 1           | Natural Density              | 17.68  | Kn/m³ |
| 2           | Saturated Density            | 21.93  | Kn/m³ |
| 3           | Dry Density                  | 10.80  | Kn/m³ |
| 4           | Specific Gravity             | 1.24   |       |
| 5           | Water Content                | 63.74  | %     |

As for the mechanical properties of soil shear strength testing to obtain the value of normal load and shear load which is then processed into a normal voltage and shear stress. Furthermore, the normal voltage and shear stress relationship curves result in deep cohesion values and shear angles as in Table 4.

In this shear strength test, simulation of the influence of water content by gradually adding water to the soil sample. The simulation is carried out constantly with water addition of 2.5% of the sample weight each time the test is performed. From the test results showed that the addition of water can only be done up to 10% of the sample weight, the addition of more than 10% causes the sample cannot be simulated again because the sample condition was destroyed by water added.

| Table 4. Mechanical properties testing results         | cohesion (Kn/m³) | slide Angle (°) | information        |
|-------------------------------------------------------|------------------|-----------------|--------------------|
| Water content (%)                                      |                  |                 |                    |
| 0.00                                                  | 50.00            | 37.00           |                    |
| 10.00                                                 | 46.71            | 35.33           |                    |
| 20.00                                                 | 43.42            | 33.67           |                    |
| 30.00                                                 | 40.12            | 32.00           | simulation         |
| 40.00                                                 | 36.83            | 30.33           |                    |
| 50.00                                                 | 33.54            | 28.67           |                    |
| 60.00                                                 | 30.25            | 27.00           |                    |
| 63.74                                                 | 23.66            | 23.67           | natural            |
| 66.24                                                 | 16.16            | 20.68           |                    |
| 68.74                                                 | 10.69            | 19.69           | simulation         |
| 71.24                                                 | 3.61             | 18.18           |                    |
| 73.74                                                 | 1.42             | 17.40           |                    |
| >73.74-100                                           | -                | -               | Cannot be simulated again |

Table 4 shows the simulated water content can be done in the range 0% to 73.74%. This means that the soil samples reach the maximum water content in the water content of 73.74%. The simulation cannot be done anymore exceeds the maximum water content.
4.1 Water Content Relation to Mechanical Properties

![Water content-Mechanical Properties Relationship](image)

**Figure 3.** Graph of relation of water content to mechanical properties (cohesion and sliding angle)

The water content relationship with mechanical properties is obtained by plotting the water content test data and the mechanical properties (cohesion and internal shear angle) into the scatter plot. Figure 3 shows that linear regression is representative enough to describe the relationship between the variables because the graph tends to form a straight line (linear). From the results of this linear regression can be concluded that the higher the water content on the soil causes the cohesion parameters and sliding angle in the lower.

### 4.1.1 Water and Cohesion Relationship

From Figure 3, we get the equation of water and cohesion relationship as follows:

\[
y = 55.713 - 0.6x_1
\]

*With \( R^2 = 0.842 \) *

With \( Y \) is cohesion and \( X \) is the moisture content. The empirical equation shows a very strong (perfect) relationship, this is indicated by the value \( R^2 = 0.842 \). The relationship of moisture content to cohesion shows a correlation with inverse meaning that the increase in water content value leads to a decrease in the value of cohesion.

### 4.1.2 Water Content Relationships and Sliding Angle

From Figure 3 we get the equation of water content relationship and shear angle in the following:

\[
y = 38.878 - 0.258x_1
\]

*With \( R^2 = 0.915 \) *

With \( y \) is the internal sliding angle and \( x \) is the water content. The empirical equation shows a very strong (perfect) relationship, this is indicated by the value \( R^2 = 0.915 \). The association of water content with shear angle in showing correlation is inversely which means the increase of water content value causes decrease to deep shear angle value.
4.2 Anaslisis Value of Slope Safety Factor
From the simulation of the water content of 0\%-73.74\%, the slope value analysis of slope security actors based on the mechanical properties of each water content simulation result. Here is the result of processing the value of slope safety factor.

4.3 Water Content Relationship to Safety Factors (SF) of Slope

| Water content (%) | Safety factor (SF) |
|-------------------|-------------------|
| 0.00              | 2.471             |
| 10.00             | 1.757             |
| 20.00             | 1.639             |
| 30.00             | 1.516             |
| 40.00             | 1.390             |
| 50.00             | 1.259             |
| 60.00             | 1.122             |
| 63.74             | 0.897             |
| 66.24             | 0.633             |
| 68.74             | 0.525             |
| 71.24             | 0.388             |
| 73.74             | 0.333             |

4.4 Water Content Relationship to Safety Factors (SF) Slope

The relationship of moisture content to SF slope is obtained by plotting the water content test and SF slope into scatter plot. Figure 4 shows that linear regression is representative enough to describe the relationship between the variables because the graph tends to form a straight line (linear).

From Figure 4 we get the equation of water content relationship to the value of SF slope as follows:

\[
y = -0.024x + 2.2678
\]

\[
R^2 = 0.9204
\]
\[ y = 2.267 - 0.024x \]
\[ \text{with } R^2 = 0.92 \]

With \( y \) is the Safety Factor (SF) and \( x \) is the water content. The empirical equation shows a very strong (perfect) relationship, this is indicated by the value of \( R^2 = 0.92 \). The relationship of moisture content to the SF slope showed a correlation between the water content and the decrease of the water content value causing the decrease of SF value.

From the graph shows that when the water content ranges between 0% to 50% so SF value > 1.25 which means slope conditions in safe category. When water content increases from 51 to 60% so SF value 1.0-1.25 which means slope conditions in the critical category. When the water content is \( \geq 63.74\% \) so SF value < 1 which means this condition indicates the slope is unsafe (landslide).

5. Conclusion
From the data analysis done it can be concluded that:
1. Addition of water content on soil samples on the slopes of the Sitinjau Lauik causeway decrease to cohesion values and internal shear angle. This decrease in value causes the weakening of the strength of the slope so that the SF value on the slope also decreases
2. The slope of the road in Sitinjau Laut is in safe condition when the water content ranges between 0 until 50%, critical when water content 51 to 60%, and unsafe (landslide) when water content \( \geq 63.74\% \)
3. High water content in the soil may cause a decrease in the level of stability (SF) on the slopes of the lava site so that it needs a way to reduce water content levels especially during rainfall such as slope or shotcrete installation.

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