The Influence of Soil Saturation and Soil Strain on Landslides

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Abstract
Landslides are the movement of masses of rock, regolith and soil from high to low places due to the influence of gravitational forces, due to the weakness of the soil structure when saturated. Humidity on a certain slope is an initial indication of a landslide. By using a humidity measuring device you can get a landslide indication value, apart from humidity there is also another indication, namely ground movement which is detected with a strain sensor. Thus, these 2 main parameters are expected to become new findings in the field of landslide disasters as an initial disaster instrumentation system.

Keywords: landslides, moisture, strain

1. Introduction

Landslides are the movement of masses of rock, regolith and soil from high to low places due to the influence of gravitational forces. In principle, landslides occur when the driving force on the slope is greater than the resisting force. The retaining force is generally influenced by the strength of the rock and the density of the soil. The driving force is influenced by the slope angle, load and specific gravity of the rock. [1] further explains that the main factors in the occurrence of landslides are slope slope and rainfall. A slope is said to be steep if the slope angle is 30. Heavy and long-lasting rainfall plays a major role in triggering ground movements (landslides). Rainwater that seeps into the slope can increase the saturation of the soil on the slope, which results in loosening the bonds of soil particles and ultimately the soil mass is carried away by the flow of water on the slope. An increase in water content causes a decrease in the value of mechanical properties (cohesion and internal friction angle) which has an impact on reducing slope stability. The risk of greater loss of life can be avoided through mitigation efforts by utilizing technological advances. Having a tool capable of measuring the main parameters of landslides can be used as early mitigation because before a landslide disaster occurs there are changes in the physical magnitude of the soil expressed by the parameters. So relatively accurate parameter measurements in determining the potential for landslides in an area are very necessary [2]. In this regard, it is necessary to develop early mitigation tools for landslides by designing landslide detection tools using FC-28 sensors and WiFi-based MCU nodes, telegrams, SMS and buzzers which are expected to be able to reduce the impact of fatalities. Several studies on the creation of early landslide detection tools that have been carried out include: A prototype of a landslide detection system using ultrasonics and infrared with SMS notification. Although there have been several studies related to landslide detectors, none has focused on soil moisture levels, so in this paper the focus is on soil moisture sensors that are connected to notifications on smartphones via telegram and SMS applications which contain information on soil moisture values, slope slopes and disaster status. as well as a buzzer as additional notification. The aim of this research is to create an early warning tool for landslides to anticipate the safety of local residents so that it is hoped that it will be able to reduce fatalities [3]. Soil Type

Each type of soil has different characteristics. For example, clay is stickier and tends to be difficult to handle, while sand is drier and crumbles easily. We will look at how these properties affect the stability of soil on slopes and what this relates to the potential for failure.

Landslides can cause considerable damage. However, the danger and risk of landslides can be minimized by providing good, sustainable risk management and accurate information about landslide events. The use of mapping the level of landslide susceptibility is one of the important keys to reducing this risk, both for individuals, the public, government and researchers [6].

Landslides or land movements occur more frequently in Indonesia from year to year, especially during the rainy season. Tectonic conditions that form high morphology, faults, easily brittle volcanic rocks and are supported by the wet tropical climate in Indonesia, cause the potential for landslides to be high. This is supported by the recent degradation of land use changes, causing landslide disasters to increase. A combination of anthropogenic and natural factors is often the cause of landslides which cause casualties and property loss. Mitigation efforts are needed to minimize the impact of landslides (Naryanto, 2017).

According to Paimin, [7] landslides occur if 3 (three) conditions are met, namely: (1) the slope is steep enough, (2) there is a watertight sliding surface below the ground surface, and (3) there is sufficient water in the soil above impermeable layer (sliding surface) so that the soil is saturated with water. [8] states that the factors that cause landslides are divided into 2 groups, namely causal factors and trigger factors. Causal factors include slope slope, rock type and soil type. Heavy rain, seismic activity such as volcanic eruptions and earthquakes are among the triggering factors. Generally, landslides have many causes, but there is only one trigger. According to Shahabi and Hashim (2015), steep slopes, high rainfall and unstable soil are the main factors in the occurrence of landslides in Southeast Asia which has a tropical climate, especially areas in mountains and valleys. [9] also explains that deforestation, population and infrastructure development continue to occur in slope areas that have a high risk of landslides. [10] said that there are 5 groups of datasets that are commonly used to assess landslide susceptibility as follows:

- Geomorphology, for example data on geomorphological sub-units and landforms,
- Topography and morphology, for example field data such as slope, aspect and curvature of slopes,
- Geology, for example data on lithology and constituent rocks, land use, and
- Hydrology, for example drainage data, water catchment areas and rainfall.

1.1 Degree of Soil Saturation

The importance of water in soil is like a sponge, soil can absorb water. The degree of saturation is a measure of how much water is sucked up by the soil. Soil that is too wet or too dry can affect the possibility of landslides. We will review how the balance between water and soil plays an important role in slope stability.

1.1.1 Saturation Degree Formula: Degree of Saturation (S) = (Pore Water Volume / Total Pore Volume) x 100%

1.1.2 Slope Stability Formula: Safety Factor (FS) = Shear Strength / Activated Shear Force

1.1.3 Lateral Sway Formula: Peak Acceleration (a) = Maximum Acceleration / Gravity

1.1.4 Formula for calculating the amount of water in the soil: Water Weight = Water Volume x Water Specific Gravity

1.1.5 Total Weight of Soil = Total Volume of Soil x Specific Gravity of Soil
Amount of Water in Soil = Total Soil Weight - Dry Soil Weight

1.1.6 Formula for Ground Movement Due to Lateral Sway: Horizontal Movement (d) = Peak Acceleration x Time^2 / 2

1.2 Slice Method

The normal force acting at a point on the circle of the landslide plane is mainly influenced by the weight of the soil above that point. In the wedge method, the landslide mass is broken up into several vertical wedges. The forces acting on each slice can be seen in Figure 1.2 below.

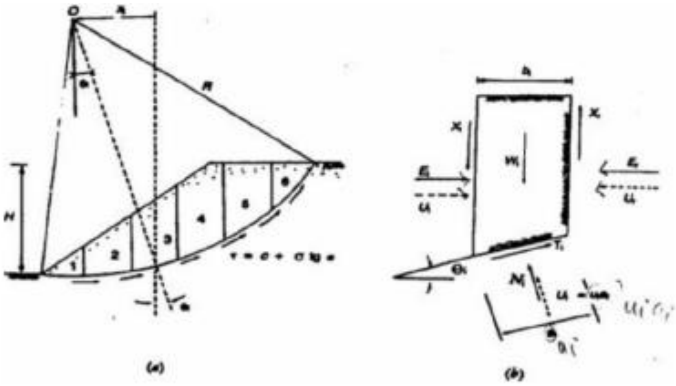

Figure 1. Forces Acting on Slices

Source: Hardiyatmo, 2010

The safety factor is the ratio of the existing shear strength (τ) to the shear strength (τm) that must be exerted to maintain the balance boundary conditions. To calculate the safety factor, the following equation can be used.

$$SF = \frac{\tau}{\tau m}$$

By considering the moment about point O, the sum of the moments due to shear forces on the failure arc AC must be the same as the moment due to the soil mass ABCD. For each slice, the moment arm W = r. sin α so that the following equation can be formed:

$$\sum Tr = \sum W . r . \sin\alpha$$

$$T = \frac{\tau}{SF} . l$$

$$SF = \frac{\sum \tau . l}{\sum W . \sin\alpha}$$

To analyze using effective stress, the following equation can be used.

$$SF = \frac{c' . La - \tan\phi' \sum N'}{\sum W . \sin\alpha}$$

1.3 Arduino

Arduino is an open source electronic device and is often used to design and create electronic devices and software that are easy to use. This Arduino is designed in such a way as to make it easier to use electronic devices in various electronic devices. The ESP8266 is a WiFi module that functions as an additional device for a microcontroller such as an Arduino so that it can connect directly to WiFi and create a TCP/IP connection. Apart from that, this module is SOC (Single on Circuit) based which means this device can also be used without the help of another microcontroller. This module requires around 3.3V power and has three wifi modes, namely Station, Access Point and Both (Both). This module is also equipped with a processor, memory and GPIO where the number of pins depends on the type of ESP8266 that we use [11]. The default firmware used by this device uses AT Command, apart from that there are several SDK firmware used by this device that are open source, including the following:
1.3.1 NodeMCU using basic lua programming
1.3.2 MicroPython using basic Python programming
1.3.3 AT Command using the AT command command
For the programming itself, we can use ESPlorer for NodeMCU-based firmware and use putty as a control terminal for AT Command. Apart from that, we can program this device using the Arduino IDE. By adding the ESP8266 library to the board manager we can easily program with basic Arduino programs.

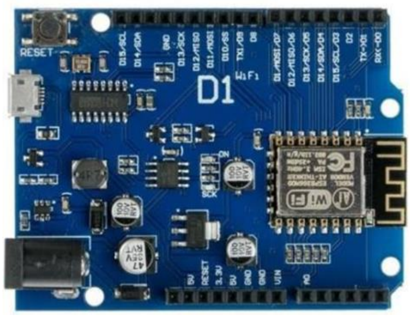

Figure 2. Arduino ESP8266 D1 WEMOS

This Arduino has several important components in it, such as pins, microcontrollers, and connectors which will be discussed in more depth later. Apart from that, Arduino also uses the Arduino Language programming language which is slightly similar to the C++ programming language. The strain gauge is an input module for Arduino. This module contains the BF350-3AA sensor, which functions as a measuring element. There is also a circuit for easier handling of resistance-strain changes, a trimmer for zero value setting and an LED indicating the connected voltage. The input supply voltage is 5 volts and the output voltage at the OUT pin is between 0 and 3.5 Volts.

Figure 3. Modul BF350-3AA

The BF350-3AA module is used as a strain measuring tool on plain steel tools [12] so that it can obtain strain values which are an indication of ground movement. To read soil moisture, the Soil Moisture Sensor module is used.

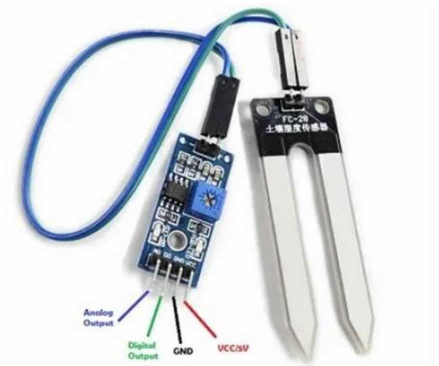

Figure 4. Modul Sensor soil moistur

2. Methods

Soil testing by considering the friction angle and soil cohesion and showing the sensitivity values of the strain and soil moisture measuring instruments with a program created using the Arduino application, in testing this instrument simultaneously with adding soil saturation using continuous and constant watering until the soil experiences landslides. The test will use 3 types of soil, namely Silty Loam, Loam and Sandy Loam at 3 stages of water irrigation with a capacity of 0.3 liters per minute.

2.1 Coding / Program Making

This program was created using the Ardiuno IDE application. The program was created to show the sensitivity values of strain and soil moisture measuring instruments.

2.2 Media Creation

The media uses a type of glass aquarium with dimensions of 50x30x30 and adds an aluminum layer which is the interaction layer between the landslide and non-landslide land.

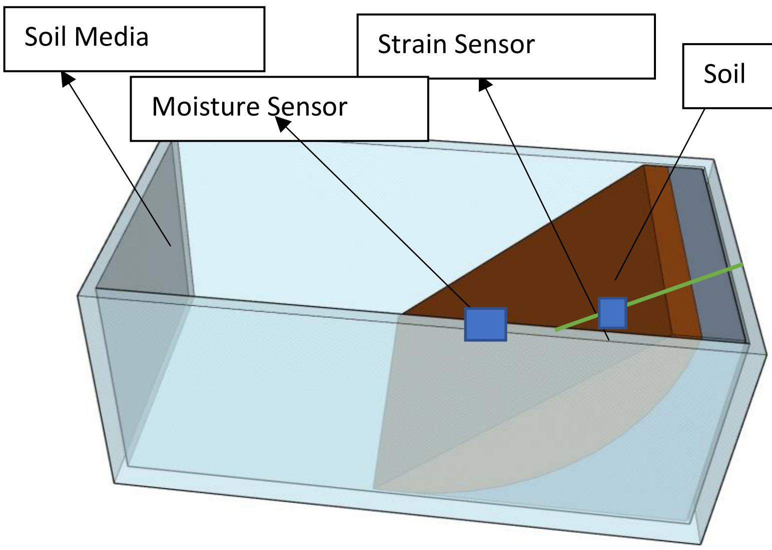

Figure 5. Media Creation

2.2.1 Soil Testing
The soil will be tested by considering the friction angle and soil cohesion

2.2.2 Sensor Installation
Component testing is carried out to ensure the tool is functioning properly according to the desired system. The test will be divided into several parts, including characterization of the soil moisture sensor, calibration of the soil moisture sensor.

2.2.3 Tool Testing
Testing this tool coincides with increasing soil saturation using continuous and constant watering until the soil experiences landslides. After that, testing was carried out on the vibrating spell to determine the lateral sway that occurred in this study.

2.2.4 Reporting
From these two landslide parameter values, data will be collected and the values will become the landslide test parameters using humidity and strain sensors.

3. Result and Discussion
Before testing this research, a strain and soil saturation detection tool was tested to ensure that the tool used was functioning properly and in accordance with the programming.
In this material test, materials are used, namely soil and water, soil as the main material in this test and water as the material for continuous and constant watering until the soil experiences landslides. In the first experiment, silty clay was used.

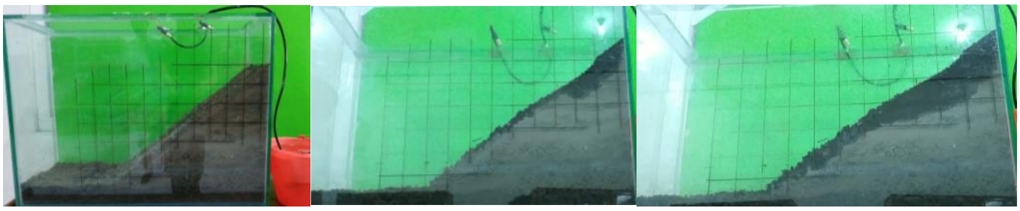

Figure 6. Before the First Test, second test at 10th minute, Third test at 20th minute

In table 4.1 it can be seen that the initial slope before the first experiment was carried out was 46^0 with a humidity of 11%. After that the first experiment was carried out which can be seen in figure 4.2.
After carrying out the second experiment, the slope was 46^0 and the soil moisture was 19% with a maximum settlement value of 5 mm. In the third experiment, the humidity value was 22.5% with a decrease of 7 mm.

The difference can be seen in the first experiment in the 2d figure below.

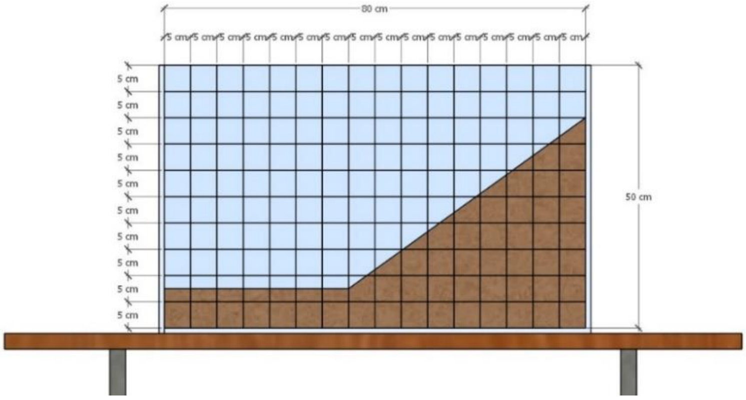

Figure 7. 2D Scenario Before the First Test

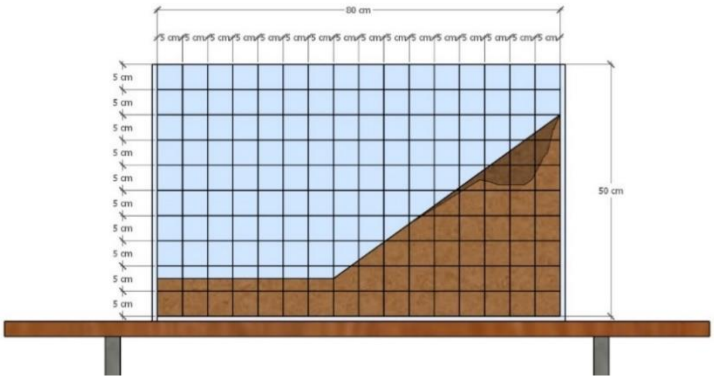

Figure 8. 2d Scenario second test at 10th minute

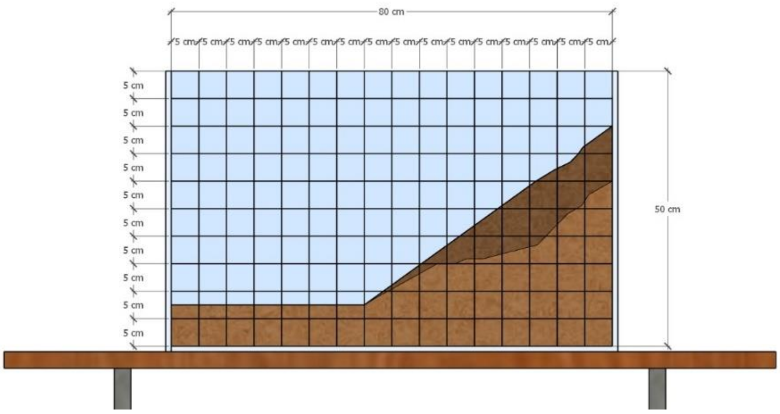

Figure 9. 2d Scenario second test at 20th minute

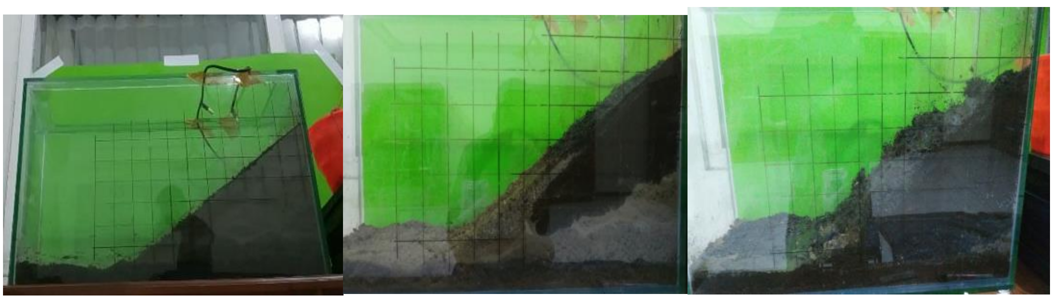

Figure 10. Before the First Test, second test at 10th minute, Third test at 20th minute

For experiments with clay soil types, you can see that the slope before the experiment was 450 and the humidity was 10%, after that a second experiment was carried out which can be seen in the Figure below. In the second experiment, the soil moisture was 22.1% with a maximum decrease of 7 mm. In the second experiment, the slope was 450 and the soil moisture was 22.4% with a maximum decrease of 9 mm.
The difference in experiments using clay can be seen in the 2d figure below.

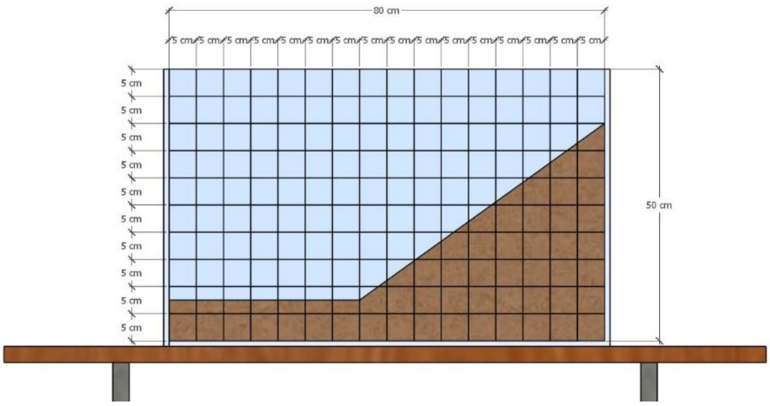

Figure 11. 2D Before the Second Experiment

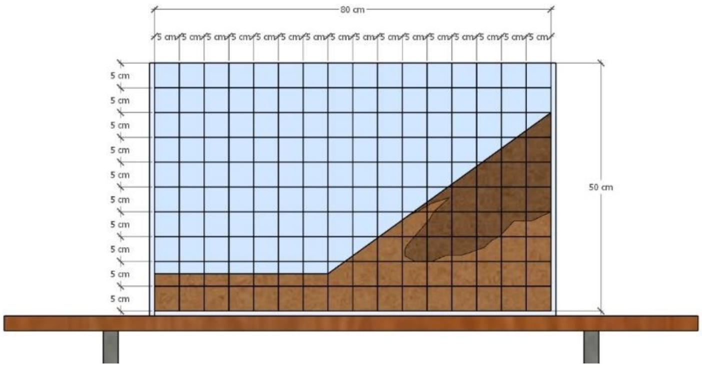

Figure 12. 2D Second Trial Minute-10

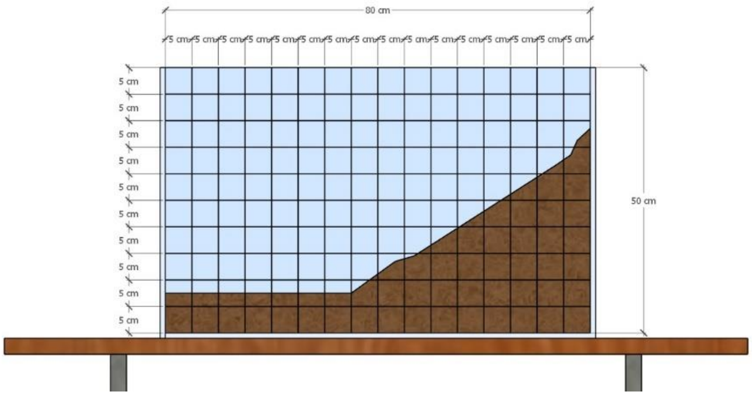

Figure 13. 2D Second Trial Minute-20

Before carrying out the third experiment, you can see that the slope of the soil is 460 and the soil moisture is 8%. Then an experiment is carried out which can be seen in the Figure below.

Figure 14. Before the First Test, second test at 10th minute, Third test at 20th minute

In the second experiment with sandy clay, it was found that the soil slope was 460 and soil moisture was 23.5% with a maximum decrease of 8mm. in the third experiment it was found that the soil slope was 460 and the soil moisture was 38.2% with a maximum decrease of 16 mm.

The difference in the third experiment can be seen in the 2d figure below.

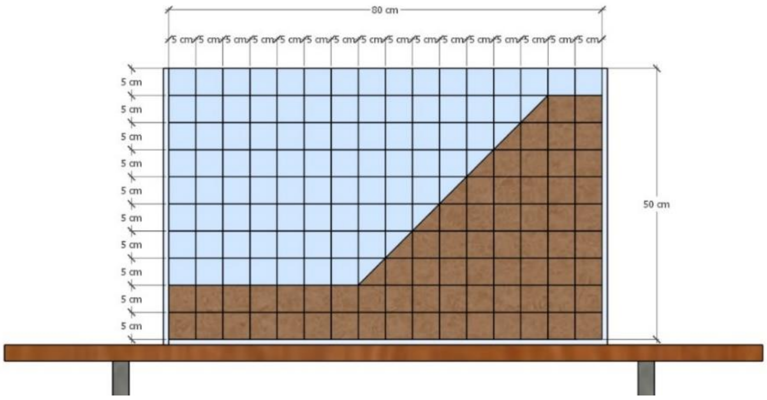

Figure 15. 2D Before the Third Experiment

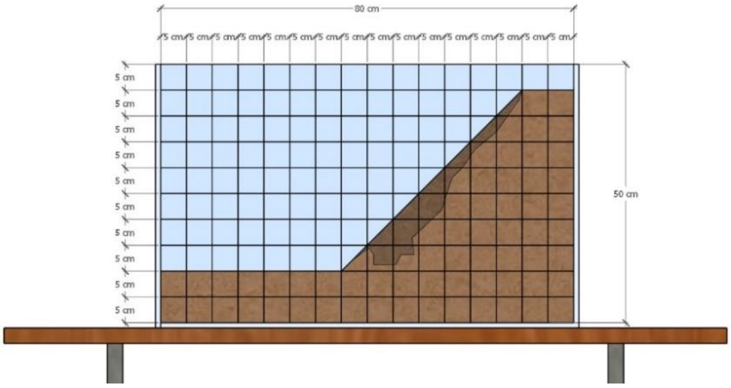

Figure 16. 2D Third Trial Minute-10

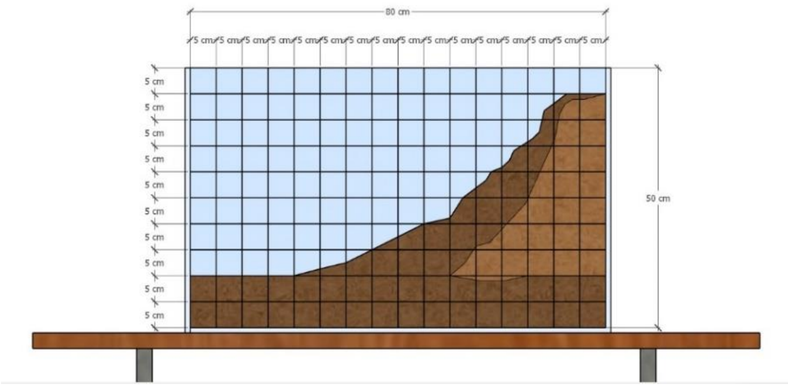

Figure 17. 2D Third Trial Minute-10

3.1 Test Results Using Arduino Microcontroller

This artiudo analysis test aims to determine soil moisture and soil strain using sensors.

Table 1. Soil Material Testing Results

Soil Speciment	Slope	Soil Saturation (%)			Maximum Strain (%)	Type Of Soil
		0	10	20		
1	46	11	19	22.5	1.5	Silty Loam
2	46	10	22.1	22.4	1.4	Loam
3	46	8	23.5	38.2	2.2	Sandy Loam

3.2 Plaxis Analysis Results

This analysis was carried out to determine the safety factor of a potential landslide area by calculating the amount of shear strength to maintain slope stability and calculating the shear strength that causes landslides, then the two were compared.

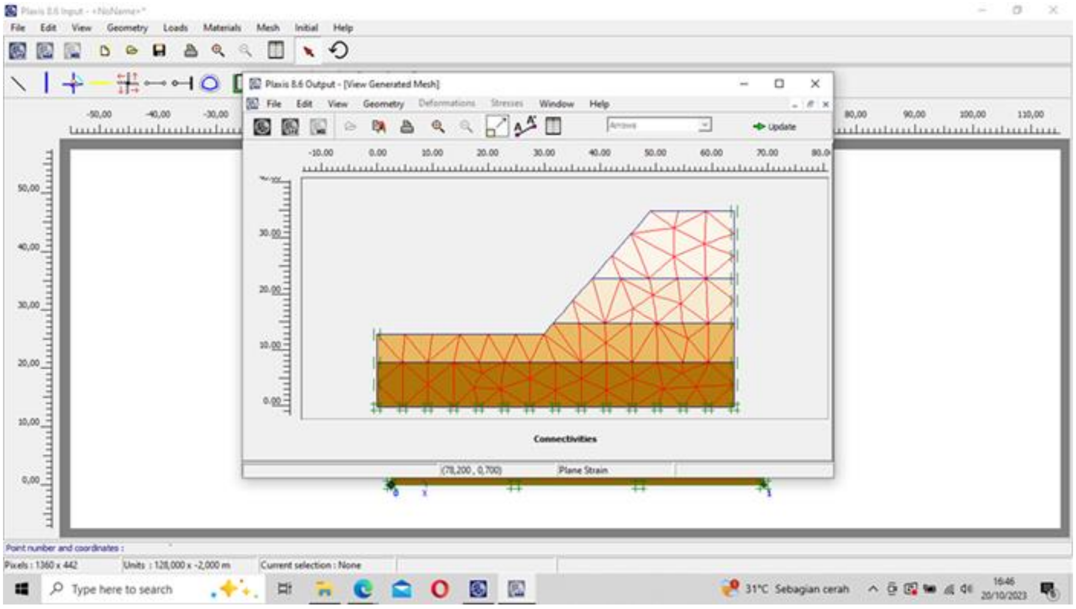

Figure 18. Output Connectivities Mesh

After displaying the connectivity mesh output, continue by clicking update. Mesh is a menu for dividing geometry into several elements. The required input for the geometry is lines, points and clusters. The elements of the resulting mesh generation are triangular with a choice of 6 points and 15 points, depending on the initial input in the general menu above. Mesh generation can divide available geometry globally, if the division of elements is done via the toolbar. The size of the element division can be selected manually according to the type and size of the object geometry.

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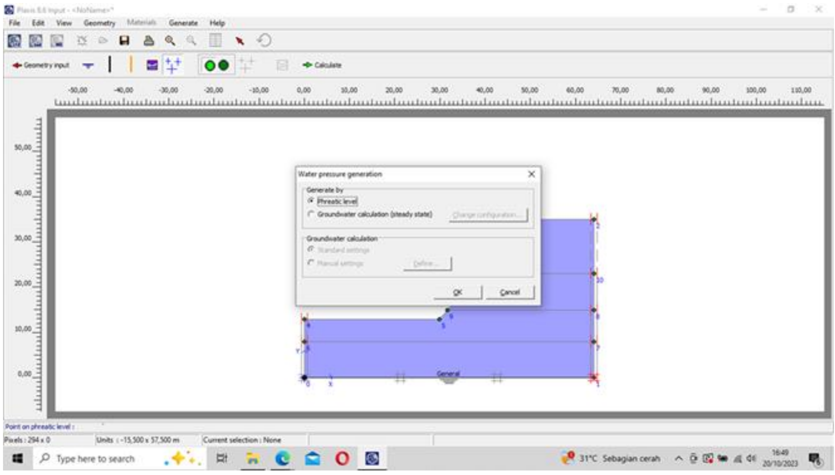

Figure 19. Insert Water Pressure Generation

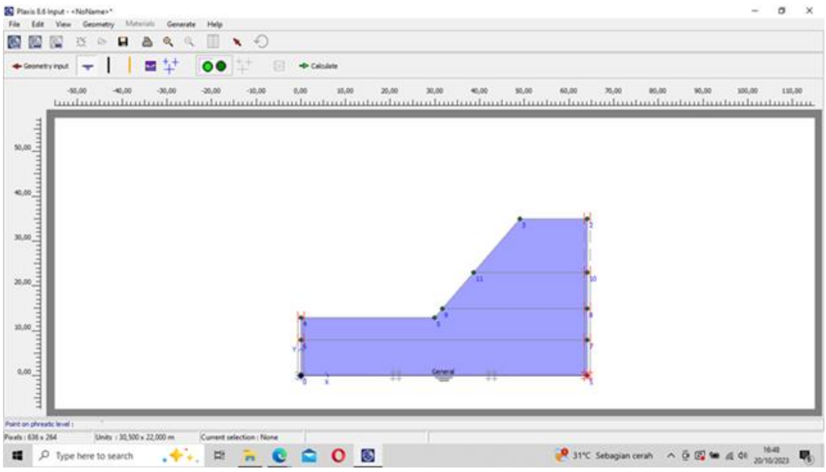

Figure 20. The condition of the water content

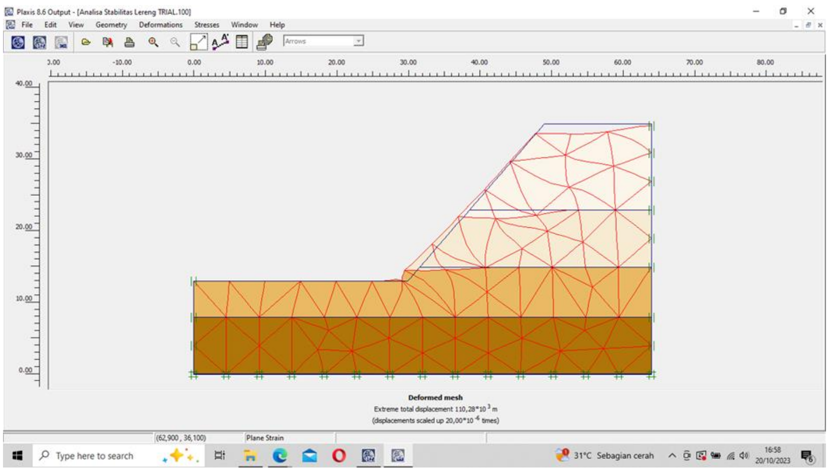

Figure 21. Output Deformed Mesh

After carrying out calculations in Plaxis, the output will appear as follows:

3.2.1 After Plaxis has finished calculating, select Excavation then select output. An figure of the soil deformation and sheet pile will appear.

3.2.2 Select the deformation menu and select total displacement. In the drop box select shading.

The results obtained from experiments on the three types of soil with variables of soil moisture and strain are as follows:

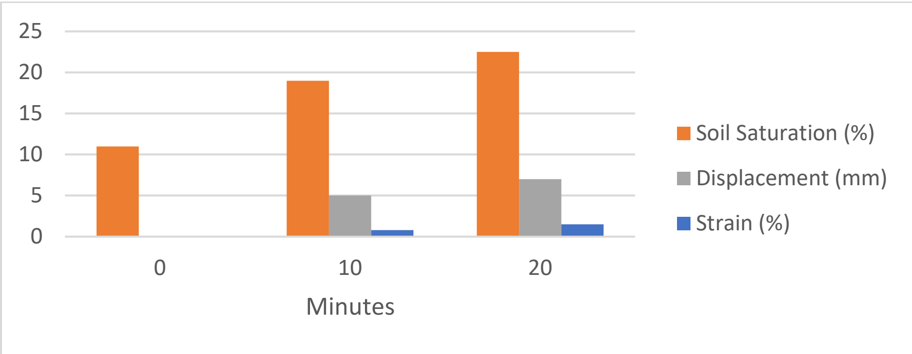

Figure 22. Test Results on Sandy Clay Soil Type

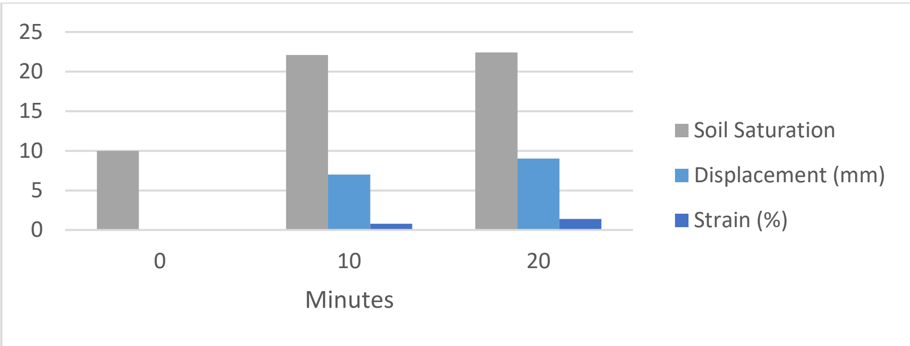

Figure 23. Test Results on Clay Soil Type

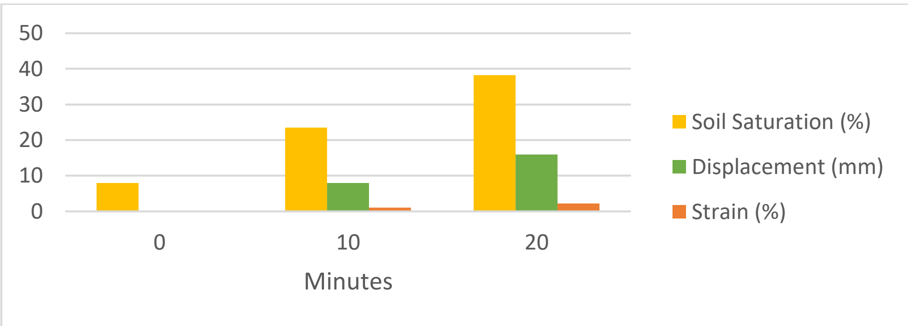

Figure 24. Test Results on Silty Clay Soil Type

From the three tests, it was found that the test on the silty soil type had the smallest soil deformation value, which means that this type of soil, when viewed from the moisture and soil strain parameters, has a low level of landslide potential.
When compared with theoretical analysis, the visible deformation results between the three types of soil are as follows:

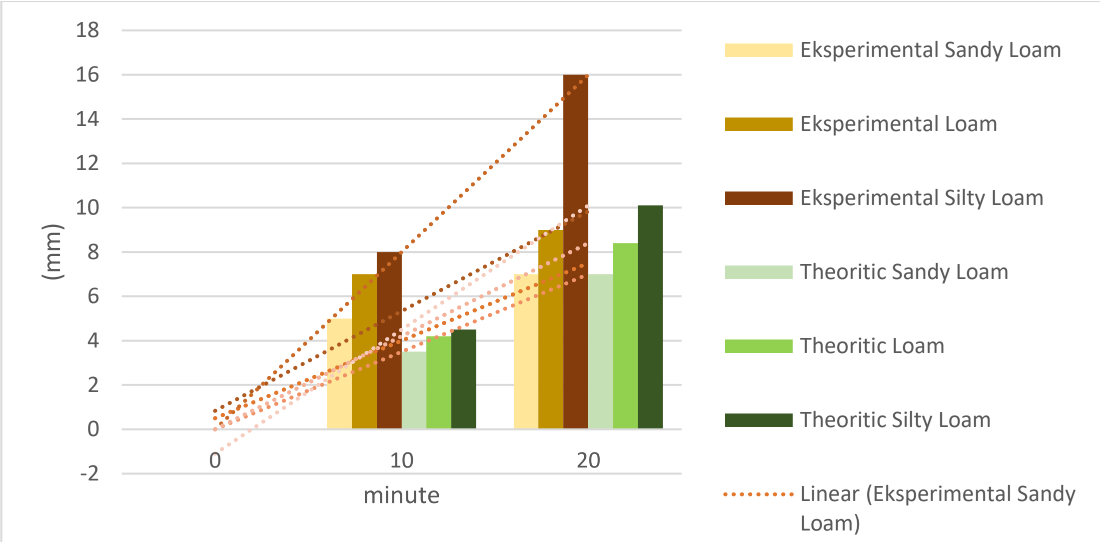

Figure 25. Comparison of Theoretical Analysis with experimental results of soil deformation due to landslide

4 Conclution

The first experiment did not experience any landslides: The clay soil which was initially dry, even after being loaded with rainwater, remained stable without experiencing any landslides. This shows that the addition of rainwater in a certain amount is not enough to change the mechanical properties of the soil to cause landslides.

The second experiment experienced landslides but on a small scale: Even though there were small landslides, there was still sufficient stability in the soil-sand mixture. This suggests that the sand mixture may have increased the shear strength and stability of the soil. Mixing sand with soil can change the geotechnical properties of the soil. Sand usually has higher shear strength than pure clay. By having sand in the mix, the soil may have better shear strength, which can prevent greater landslides.

The third experiment with the addition of water discharge and sand soil in a saturated state. Saturation of the soil with water changes the soil properties in a significant way. When soil reaches water saturation levels, this can reduce shear strength and make the soil more susceptible to sliding. Further increase in water discharge resulted in landslides, although not on a large scale. This indicates that sand-mixed soil that has reached water saturation levels becomes more fluid and less stable, but the residual strength of the soil may still be sufficient to prevent more serious failures. The landslide that occurs may not reach the point where there is serious damage to the structure or surrounding environment. In essence, this third experiment shows that soil type influences soil landslides.

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