Slope stability analysis through variational slope geometry using Fellenius Method

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Abstract. In previous research about analysis of slope stability on Lalingato Area, Tirawuta Districts, Kolaka Timur Regency, Sulawesi Tenggara, has been obtained slope instability with factor of safety between 0.38 - 0.64. This instability is caused by activity of geological structure, such as; joint. In the other hand, the effect of slope between 44 - 67 degrees are very influential. The study has conducted a theoretical investigation of the variation of slope form to minimize the landslide of slope. There were two schemes to investigate of slope stability as follows; (a) slope variation, and (b) slope terraces variation. The research has used Ms. Excel and Slide software. Based on the result of research was obtained that slopes with terraces will be easily stable. Meanwhile, if angle of the terraced slopes was given 35° - 44°, so factor of safety was 1.28 - 1.75. The future about the research will be developed to investigate slope stability with inhomogeneous material.

1. Introduction
In general, landslides are the process of slipping or moving a part of the soil. In addition to high rainfall, landslides also as a result of steep topography in the other cases. Both factors are main factor of landslides. In our previous research about analysis of slope stability on Lalingato Area, Tirawuta Districts, Kolaka Timur Regency, Sulawesi Tenggara, show that steepness of topography could be effect on unstable of soil conditions and easily to landslides [1]. There are many techniques to solve this problem, altering or manipulating topographic form is one of the suitable solutions. This technique has a high risk if geometry of topography is not calculated accurately, such as bringing up many new landslide’s spots and in the worst conditions can cause an environmental damage.

In engineering area, there is a realistic and precise offer that is the slope stability analysis. This is a very important field in geotechnical engineering since could investigate and understand landslides potential on a slope. Furthermore, the slope stability analysis could be used to design a safe slope and stable in various conditions [2]. Some main methods and very familiar to analysis slope stability, such as numerical method [3-5] and also the traditional method or the limit equilibrium technique [3,6,7]. The limit equilibrium technique is a pioneer and conventional method in slope analysis. The technique is simple but given a good result. The method used the failure criterion, The Mohr-Coulomb Theory,
which assumed that the shear strength ($\tau$) and the normal stress ($\sigma$) have linear relationships. One kinds of variance of the technique is Fellenius Method, Ordinary Method of Slice or Bishop Simplified [8]. The method was developed by Fellenius, he assumed that the potential sliding mass has been divided into sub vertical slice and each slice had own weight ($W$) [9, 10].

Based on the explanation above, the authors would investigate variational effect of slope geometry using Fellenius Method. In another hand, the research could be contribution as reference to local government for development of Kolaka Timur Regency. This article was divided into four section. The first section about background of study. The second section will introduction method of the study and also illustration of research location. Meanwhile, the last two sections will show result and conclusion.

![Figure 1. Illustration of slice in Fellenius Method.](image1)

![Figure 2. Description of the forces on each slice](image2)

2. Methodology

2.1. Fellenius Method

In this section, we will introduce Fellenius method as a method of the study. As mentioned earlier that this method divided the potential sliding mass into sub vertical slice (see Figure 1). It is meant to obtain and to calculate the factor of safety ($F$) each slice easily. Based on the information on the Figure 2, the factor of safety of it can be defined as follow:

$$F = \frac{\tau}{s}$$ (1)

$$F = \frac{W \cos \alpha \tan \phi + cL}{W \sin \alpha}$$ (2)

Here, $W$ and $\alpha$ is different each slice. For $n$-slice, the factor of safety ($F$) is defined as follow:

$$F = \frac{cL + \tan \phi \sum_{i=1}^{n} (W \cos \alpha)}{\sum_{i=1}^{n} W \sin \alpha}$$ (3)

where $c$, $W$, and $L$ are cohesive force, own weight of materials and length of arc $AC$, respectively. $\alpha$ is angle between the tangent to the center of base of each slice and the horizontal and $\phi$ is effective angle of internal friction. $n$ is number of slices.

2.2. Description and Physical Parameter of Soil

In Lalingato Area, the texture soil is clay-sand, well graded, low weathering rate, and also formed by a silica precipitate. The soil color is dark-red (like a brick) and dark-yellow. Found in various kinds of
climate with altitude from sea level up to 200 m. Based on this information, the type of soil is litosol that formed from schist [11].

In previous study [1], our research used three observation stations which all station was unstable and potentially landslides. The following is the factor of safety value for each station:

Table 1. The factors of safety each station.

| Stations  | Slope angle | The factor of safety |
|-----------|-------------|----------------------|
| The First | 53°         | 0.38                 |
| The Second| 67°         | 0.39                 |
| The Third | 44°         | 0.64                 |

Meanwhile, physical properties i.e. cohesive and effective angle of internal friction for each station were given through laboratories experiment as follows:

Table 2. The physical properties each station.

| Stations  | Cohesive  | Effective angle of internal friction |
|-----------|-----------|--------------------------------------|
| The First | 0.097 kN/m² | 19.95°                              |
| The Second| 0.001 kN/m² | 20.35°                              |
| The Third | 0.22 kN/m²  | 31.59°                              |

Figure 3. Slope stability in station 1.

Figure 4. Slope stability in station 2.
3. Results and Discussion
Since our previous studies about slope stability analysis in Lalingato area have indicated that slope condition was unstable and potentially landslides. To get stable condition, we have already varied the slope angle and geometry of slope.

3.1. Slope variation
Here, the angles of slope were changed to smaller for each station. Minimization of angle were different on the first, second, and the third station, those were 37°, 41°, and 35°, respectively. Based on analysis result using Slide Software is obtained the factor of safety \( (F) \), each of these values were 0.35, 0.49 and 0.77. Let’s see figure 3 - 5 to get more specific information. Conceptually, those numbers indicated that the slopes were unstable since the values of the factor of safety is less than 1.0 \((F < 1)\). Furthermore, if the values are compared the factor of safety standard that proposed by Joseph E. Bowles, they were more unstable [12]. Based on these conditions, we change the slopes become terraces form. The factors of safety are expected to become larger and the slopes are stable expected to be stable.
3.2. Slope terraces variation

In this section, we used 4 - 6 terraces for each station which the angles have been varied. First, the used angles were similar with previous study [1]. Second, its angles were similar with the used angles on section 3.1.

On Lalingato area, the used of terraces with similar angle slopes on previous study, 53°, 67°, and 44°, was not effective for all. By Slide software which was showed on figure 6 – 7, we obtained that station 1, 2, and 3 had the factor of safety (F) as follows; 0.78, 0.59, and 1.28, respectively. Here, even though station 1 and 2 was unstable slope condition, station 3 was safety. This was safety because F was bigger than 1.0 (F > 1.0).

Since some slopes were unstable, we be supposed to minimize the angle of terraces slope. Result of minimize the angle of terraces slopes as follow:

| Stations     | The angle of terraces | The factor of safety |
|--------------|-----------------------|----------------------|
| The First    | 37°                   | 1,14                 |
| The Second   | 41°                   | 1,20                 |
| The Third    | 35°                   | 1,75                 |

Figure 7. Stability of the terraces slope on Station 2 using Slide Software.

Figure 8. Stability of the terraces slope on Station 3 using Slide Software.
Meanwhile, illustration figure of the factor of safety each slice was shown in figure 9 – 11.

**Figure 9.** Stability of terraces with the angle slope 37º on station 1.

**Figure 10.** Stability of terraces with the angle slope 41º on station 2.

**Figure 11.** Stability of terraces with the angle slope 35º on station 3

Based on the safety factor value in Table 3, all station was stable which is mean those on the safe category. Furthermore, station 2 have terraces angle bigger than station 1, it’s the factor of safety (F) bigger than station 1. These phenomena happen as a result by effective angle of internal friction (\(\phi\)) each station.
4. Conclusion and Future Work

There are some conclusions in our study as follows:

- Variation of the slope angle and form of terraces have been investigated. Effect the slope angle did not contribute significantly but not for the form of terraces.
- In slope stability analysis, the effective angle of internal friction ($\phi$) had more contribution to keep stability of slope.

The future work, we will investigate effect number of terrace slope and effect of inhomogeneous is very interesting. The other method will be presented soon, such as; Finite Element Method (FEM) and Discrete Element Method (DEM).

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