Slope stability analysis in various Terraces model (case study: Sendangmulyo, Tirtomulyo District, Wonogiri Regency)

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Abstract. Wonogiri has various contours. Steep slopes dominate some areas. Hence it has a high possibility to occur landslides. There are still a lot of people living under the slopes. Therefore, this research is essential for disaster mitigation purposes. The study aims to know how the value of the slope safety factor changes with construction terraces design. The research was conducted by collecting secondary data and improving the Terraces construction carried out. The data was analyzed in the limit equilibrium method to provide conditions before and after the rain. The models were tried with several Terraces variations on the slope to obtain the most optimal design. The results used a simplified Bishop method. The design of terraces on the slopes of Sendangmulyo Wonogiri Village shows that the SF value increase is only for the conditions before a rain. In contrast, the states after the rain do not yield a safety condition. The SF value increases if the number of steps increases, whereas the more step height increases, the less the SF value will be.

1. Introduction
Wonogiri is the regency in central java that has various contours. Because of this condition, the region has a high probability of obtaining a landslide. This study was located in Sendangmulyo, Tirtomoyo district, Wonogiri regency. It has a precipitous zone and different elevations that caused the high vulnerability of landslides. Wonogiri has high rainfall, and landslides occur most when it rains. Hence, it must analyze the effect of slope stability in terms of conditions before and after the rain [4]. There are many efforts to prevent landslides, one of which is terraces. The terrace was the best and adequate for the Wonogiri area. Besides, Based on [15], terraces also prevent erosion, inexpensive, and maintain slope stability. Furthermore, modeling the terraces on the slope guard has been done for a long time, thus facilitating the work [8].

This research uses secondary data (Slope geometry and soil properties) from [4]. The Terraces models were developed by adding to the original slope angle from [3, 11]. Previous research is used slope in 30° existing models, and for the current analysis, the existing slope model was analyzed in 30° and 60°. The slope stability analysis results that produce the most critical safety factor were used as a reference in this analysis. The results of this study are expected to provide several slope designs to obtain a Safety factor ≥ 1. This research offers several variations of the...
Terraces design that can be used as an alternative for protecting slopes. Because the unstable terrace in one particular part can affect the slope’s stability [7,12], variation in current research takes the design of several variations of the step [9]. This study’s output is several alternative configurations of the Terraces model and safety factors from each design to reduce landslides’ vulnerability.

2. Literature Review
The safety factor in limit equilibrium is defined as the ratio between the maximum shear strength and the required shear strength to restrain stability, the power in the limit equilibrium state [1]. Classification from SF value and affect the condition shown in Table 1. Table 1 depicts the minimum SF value for the stable condition. 1.2 is the minimum SF to consider that the slope is safe. The limit equilibrium analysis is provided in Eq (1).

$$SF = \frac{\tau_f}{\tau_d} = \frac{c + \sigma_n \tan \phi}{c d + \sigma \tan \phi_d}$$  \hspace{1cm} (1)

where $\tau_f$ is soil average shear strength and $\tau_d$ is average shear strength in failure slope. $c =$ cohesion (kN/m$^2$), $\sigma =$ sliding angle ($^\circ$), and $\sigma_n =$ normal stress.

| Safety Factor | Slope Condition |
|---------------|-----------------|
| $SF > 1.2$    | Stable          |
| $1.07 \leq SF \leq 1.25$ | Critical |
| $SF \leq 1.07$ | Unstable        |

Terraces are a slope model for soil and water conservation designed to shorten the slope’s failure length or reduce the slope angle by excavating and filling land across the slopes. The purpose of Terraces is to reduce runoff speed, lose soil, and increase water infiltration [14]. Terraces are often used in hilly and prone areas to landslides. Terraces avoid soil erosion by rainwater flow. The number of terraces may have effects on slope stability.

3. Methodology
This research was conducted in Sendangmulyo Village, Wonogiri Regency, was started by collecting secondary data (Soil parameter; $\gamma_b$, $\gamma_{saturated}$, $\sigma$, and $c$.) from previous studies [8] [10–12]. Soil test results in Soil mechanic laboratory UNS. The data is the soil parameter in
Table 2. Based on Table 2, the soil of the slope is noncohesive because cohesive = 0. Whereas cohesion and $\sigma$ are important parameters for calculating stability.

| Parametric | Unit       | Result |
|------------|------------|--------|
| $w$        | %          | 19.38  |
| $\gamma_b$| kN/m$^3$   | 17.81  |
| $\gamma_{sat}$| kN/m$^3$ | 19.15  |
| $G_s$      | -          | 2.66   |
| $\phi$     | $^o$       | 37.47  |
| $c$        | kN/m$^2$   | 0      |
| $h_{sat}$  | m          | 0.473  |

The critical slope angle is 60 degrees based on [8] as Fig 1. Fig 1 is the existing critical model in Sendangmulyo, Wonogiri. The new model in current research is made several variations of the terraces by changing the number of steps and height of the actions based on existing geometry.

**Figure 2.** Slope models relationship to SF value in all conditions

4. Result and Discussion
In this research, slope stability analysis was carried out in the conditions before and after the rainfall. Analysis of slope stability due to rain loads are modeled with saturated soil condition ($H_{sat}$), the data is obtained from [5], the most critical requirements. The results of the analysis shown in Table 3.

Table 3 shows the detailed slope dimension of geometry in various terrace model. The terrace model is in 1-10 variation in different layers of slope thickness. All soil levels are taken by dividing the total height of slope; from 1/2$H$-1/5$H$ and step between 2-5 for each variation. SF in all models for the slopes of 30$^o$ and 60$^o$ in the conditions before and after the rainfall is given in Figure 2.
Figure 2 describes the relationship between SF to all the models of the terrace. All the SF in different conditions showing the same trendline. SF value in variation 1-4 rises gradually but decreases dramatically in variation 5 and increases slightly in interpretation 10. Based on [13], the soil shear stress is restrained at the top of the terrace. This would lead to the condition of 1/3H in variation 5 have a minimum of SF.

Slope with 30° before rainfall on all Terraces models has SF above Bowles’s recommendation, which means less vulnerability of landslides. On the other hand, the result of rainy conditions provides SF under Bowles’s proposal. According to [6], the limit equilibrium analysis for infinite slope in rainfall conditions commonly obtains a failure slope. Because of this condition, there is a high potential for landslides even though the terraces have been repaired. Slope Improvement in 60° slope in post-rainfall conditions with several models yields SF value under Bowles’s recommendation. Hence, the variation is not sufficient to prevent landslides. Meanwhile, in the requirements before the rain, some variations provide SF over the Bowles’s recommendation, landslides will not occur accordingly.

4.1. The relationship between SF and the number and height of the step
The variation of the terrace has been analyzed using the limit equilibrium method for any layer model variation. The result of n-step variation models before and after rainfall is shown in
Figure 3 and Figure 4. Figure 3 shows the relationship between SF and the terraces in each layer before rainfall conditions. According to Figure 3, The trendline has similarities in both cases. There is an increase in the SF value when the number of steps also. SF before rainfall at n-step 2 and 3 for slope 60 has a safety factor below 1.25 (Bowles recommendation). This means that the vulnerability for landslide will occur. Meanwhile, other n-step variations have a safe value. SF range in 1.5-2.3 for slope 30 and 0.7-1.4 for slope 60. The SF value difference before rain conditions reaches about 39% to slope 30 and 95% in slope 60. The other factor that gives the effect of SF is the degree of slope. Rising of one degree in slope design can cause slope failure [2]. Therefore, the number of terraces significantly affects to SF value of slope stability in condition before and after the rainfall. The more number of terraces, the more stable the slope will be.

Table 3: Variation of Terraces Model

| Condition     | Variation | n step | H step | n-layer height | SF  |
|---------------|-----------|--------|--------|----------------|-----|
| Before rainfall | Variation 1 | 2      | 1/2H,1/2H | 5               | 5   | 1.588 | 0.742 |
|               | Variation 5 | 3      | 1/3H,1/3H | 5               | 3.33 | 1.694 | 0.851 |
|               | Variation 6 | 3      | 1/4H,1/4H | 5               | 2.5  | 1.734 | 1.1   |
|               | Variation 2 | 3      | 1/5H,1/5H | 3.33            | 3.33 | 1.764 | 1.19  |
|               | Variation 7 | 4      | 1/2H,1/5H | 5               | 2    | 2     | 1.85  | 1.311 |
|               | Variation 8 | 4      | 1/2H,1/3H | 3.33            | 2.5  | 2      | 2     | 2.018 | 1.307 |
|               | Variation 3 | 4      | 1/2H,1/4H | 2.5             | 2.5  | 2      | 2.03  | 1.32  |
|               | Variation 9 | 5      | 1/2H,1/5H | 3.33            | 2    | 2      | 2     | 2.147 | 1.4   |
|               | Variation 10| 5      | 1/3H,1/5H | 2.5             | 2    | 2      | 2     | 2.17  | 1.398 |
|               | Variation 4 | 5      | 1/4H,1/5H | 2               | 2    | 2      | 2     | 2.205 | 1.447 |

| After rainfall | Variation 1 | 2      | 1/2H,1/2H | 5               | 5   | 1.042 | 0.481 |
|               | Variation 5 | 3      | 1/3H,1/3H | 5               | 3.33 | 1.09  | 0.525 |
|               | Variation 6 | 3      | 1/4H,1/4H | 5               | 2.5  | 1.11  | 0.6   |
|               | Variation 2 | 3      | 1/5H,1/5H | 3.33            | 3.33 | 1.135 | 0.663 |
|               | Variation 7 | 4      | 1/2H,1/5H | 5               | 2    | 2      | 1     | 1.2   | 0.76  |
|               | Variation 8 | 4      | 1/2H,1/3H | 3.33            | 2.5  | 2      | 2     | 1.234 | 0.764 |
| After rainfall | Variation 9 | 5      | 1/2H,1/5H | 3.33            | 2    | 2      | 2     | 1.3  | 0.8   |
|               | Variation 10| 5      | 1/3H,1/5H | 2.5             | 2    | 2      | 2     | 1.329 | 0.826 |
|               | Variation 4 | 5      | 1/4H,1/5H | 2               | 2    | 2      | 2     | 1.339 | 0.84  |

Figure 4 describes the same thing as Figure 3, yet different in the rain conditions. Figure 4 is an analysis of slope stability after rainfall. The graph illustrates SF value rise slightly for each order of terrace models. Based on Figure 4, the SF value above 1.25 (Bowles recommendation) is in n-step 5 on a 30-degree slope after rain. Whereas, SF in other condition have e SF below 1.25 (high vulnerability of landside). The result suitable to [?] that rainfall is one of the several main factors to trigger slope failure.

5. Conclusion

Based on the result and discussion of slope stability analysis with terracing, it can be concluded as follows: Design of terraces on the slopes of Sendangmulyo Wonogiri Village shows for several terraces models the increase in the SF value is only for the before rain conditions. In contrast, after the rain does not obtain a safety condition. SF will increase if the number of steps increases. Yet, the more step height increases, the less SF value will be.
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