Back Calculation of Slope Stability in Batu Gadjah, Ambon City Using the Solution of Analytical and Finite Element Method

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Abstract. At the time of entering the rainy season from year to year in the Maluku region, especially the Ambon Island area experienced an increase in landslides due to rainfall, human activities such as excavation under the slopes, loss of vegetation, changes in land use and so on. The disaster that occurred on RT.03 / RW.01 Batu Gadjah Village, Sirimau Subdistrict, Ambon City, on June 1, 2018, ago, still leaves a trace of damage that until now. In this study, the researcher will analyze the slope (deformation that occurs) in the 2D model using Finite Element Method (FEM), by reviewing the weathering conditions of the rocks that are read from the results of the drill data in the form of soil properties and variations in rising groundwater levels. The results of calculations using FEM on dry slope conditions obtained the value of safety factor (FS) 1.10 and the analytical of FS value 1.18. This FS value indicates that the study area is still prone to landslides. Then the calculation with FEM on the wet slope conditions by rainwater obtained an FS value of 0.90, and analytically the FS value of 0.99. This FS value indicates that the research area has experienced a landslide.

1. Introduction

The disaster that occurred in RT.03 / RW.01 Batu Gadjah Village, Sirimau Subdistrict, Ambon City on June 1, 2018, still left a trace of damage that can be seen today and can be seen in the field. A cursory observation in the field shows that the condition of surface soil layers is compacted volcanic rock, with weathering thick up to 5 meters and obtaining a steep slope of up to 75 with a height difference of 22 meters above sea level (m.asl). Landslides that occur in this region have a non-horizontal surface (circle) and are influenced by gravity so that it hits the house. There were no fatalities, but one family was displaced (Fig. 1).

Events that occur in landslides are in the rainy season from May to July with high rainfall. An avalanche triggering rain is rain that has a certain rainfall, so that rainwater can seep into the slopes and push the soil to landslides. This type of heavy rain will only be very effective in triggering avalanches on slope cover material that easily absorbs water, such as in sandy loam, silt and sandy soils [1]. This happens when there is loading from rainwater and the soil becomes saturated causing the greater gravity and the total shear resistance in the slip plane is exceeded, then an avalanche occurs. For normal types of rain, for example, rain is less than 100 mm per day. This type of rain if it
Lasts for several weeks to several months can effectively trigger avalanches on slopes composed of more watertight soil, for example, slopes with clay soil [2,3]. On this slope landslides generally occur starting in the middle of the rainy season, for example in May to August [4]. Landslide research related to the factors above has often been done as several examples above. Existing research is still around 2D plane strain modeling (two dimensions). Furthermore, in this study, the researcher will conduct an analysis of the landslide (deformation that occurs) in the 2D model using Finite Element Method (FEM), by reviewing the weathering condition of the rock which is read from the drill data in the form of soil properties data and variations in groundwater level rise. Reverse landslide calculations that have occurred were carried out in this study to simulate the mechanism of slope failure using FEM. Post-landslide slope stability analysis is carried out to evaluate the alternative structure for handling the slope.

![Figure 1](image1.png)

**Figure 1.** (a) Post-landslide slope conditions on June 1, 2018, and (b) illustration of slope conditions before landslides and post-landslides

2. **Theory and method**

The volume of the landslide mass slides down the slope until it reaches the foot of the slope and settles. This process of the derailment is known as a mass movement [5]. The slope forming material is in the form of debris such as the mass of host rock, soil layers, man-made piles or a combination of various types of material [6]. Soil movement is the process of transferring the mass of soil or rock in an upright, horizontal or tilted direction to its original position due to the influence of water, gravity, and external loads [5, 7]. The ground movement or sliding movement according to Cruden in [6] is similar. The movement of the land carrying landslide material at high speed causes damage to infrastructure and the environment, fatalities and substantial property losses. The general causes of landslides in the study area include the steep slopes and without anchoring, the weak fields that have the potential to become slippery fields, the compilers of the water-saturated slope, contaminated with local community waste and the existence of uncontrolled land-use change.

2.1. **Study area**

The field data collection survey was located at the site of a landslide in RT.003 / RW.01 Batu Gadjah Village, Sirimau Subdistrict, Ambon City which was located at coordinates 03°04'5.52″ LS, and 128°01'7.82" BT with an altitude of 14.0 - 45.0 meters above the surface sea (m.asl) as shown in Fig. 2. In general, the stratigraphy of the dominant research area is composed of Ambon volcanic rocks in the form of surface rocks in the form of alluvium rocks and igneous rocks in the form of Ambon granite rocks [8]. In terms of physiography, where the morphology is composed of low-lying hills to moderate rolling hills with a slope above 700 and elevation reaching 45 m.asl.
2.2. Data acquisition
The Field data acquisition includes natural physical parameters such as geological conditions, slopes, land-use, types, and dimensions of landslides, and non-natural parameters in the form of dialogue with the community. Geometry measurement consists of measuring the length, width of the landslide area, the thickness of the soil layer, the center of the landslide rotation, and the distance of the landslide runoff. Drilling to take soil samples using shallow drill aims to determine the structure of the soil layer, depth of groundwater level, and the nature of the soil. Soil samples were taken at the study site, then tested in the laboratory to get the physical properties of the soil.

2.3. Slope stability evaluation of solution method
Evaluation of slope stability is carried out on two approaches namely, slope conditions before landslides and post-landslide slope conditions using analytical solutions and Finite Element Method (FEM). The slope geometry for these two conditions was redesigned based on the geometry of the landslide in the field. For trial and error efforts on slope stability, the center points of landslides in the form of circular arcs must be determined in advance through numerical and analytical calculations. The determination of the slope safety factor is based on Fig. 3, where the Fellenius cutting method divides the slope into several slices [9, 10], so that moment equilibrium is used, the FS slope safety factor, is expressed as

Figure 2. Topographic map of the study area. (a) Landslide area (Source: Google earth, 2019), (b) Topography of the study area
\[ F_S = \frac{\sum_{i=1}^{n} \left[ c_i + (W_i \cos \beta_i - u) \tan \phi_i \right] t_i}{\sum_{i=1}^{n} (W_i \sin \beta_i)} \]  

where \( c_i \) and \( \phi_i \) are the soil slope cohesion (kPa) and the internal friction angle (degrees), gravity is the gravity weight of the ground slope (N), and \( t_i \) is the arc length of the slope of the ground slope (m), \( \beta_i \) is the angle between the tangent line of the slip surface of the ground slope and the horizontal line (degrees).

Figure 3. Fellenius slice method [9]

Because the drilling only reached a depth of 3 m, it was necessary to redesign the geometry of the landslide field based on field data to try to determine the failure of the approach slope by try and error [6]. The finite element mesh used in this analysis is as shown in Fig. 4.

Figure 4. Slope geometry model with FEM for the three layer model [6]

The first step in our analysis are concerning about selected the numbers of element and selected these value when the number of element became independents of solution, in this case any increment in the number of element dose not effected on the values of solution in domain of analysis the number of elements is selected from mesh generation from change in phreatic surface [11]. Slope evaluation was carried out with FEM using software from [12] and verified with FS analytic results. By utilizing
FEM (Fig. 4), no assumption of landslide fields is used, FS slope is obtained by searching for weak fields in the soil-rock structure. FS is obtained by gradually reducing the cohesion value and shear angle in the soil, so that the soil-rock layer experiences slipping. Automatic FS values are obtained using FEM [12, 13] as in the following equation:

$$F_S = \sum M_{sf} = \frac{\tan \varphi_{\text{input}}}{\tan \varphi_{\text{reduction}}} = \frac{c_{\text{input}}}{c_{\text{reduction}}}$$

or,

$$\sum M_{sf} = \frac{\text{shear strength available}}{\text{shear strength during landslides}}$$

where $\varphi_{\text{input}}$ = shear angle in soil (degrees), $\varphi_{\text{reduction}}$ = reduced shear angle in (degrees), $c_{\text{input}}$ = soil cohesion (kPa), and $c_{\text{reduction}}$ = reduced soil cohesion (kPa).

3. Results and discussion

In general, landslides that move on the slip plane are caused by the gravitational pull of the earth and the component of gravity which is parallel to the surface of the inclined plane. In the study area, these components come from weathered rocks and break down easily when exposed to rainwater causing the rocks to become saturated with water, and the amount of rain water that seeps into the soil due to high rainfall with a long duration, and the presence of large trees and settlements both on and beside the slopes. If the surface of the inclined plane is rough, then there is a frictional force in the opposite direction to the direction of motion of the landslide mass following the slope. Landslide-type soil movements in the study area have occurred, and no one can know exactly when the landslide occurred.

3.1. Slope geometry

Data acquisition in the landslide field begins with measurements on the landslide geometry to get the dimensions of the landslide. Measurement results in the form of length, width of the landslide, thickness of the soil layer, the center of rotation of the landslide, rock samples taken by hand drill and the height of the landslide flow from the landslide crown to the foot of the landslide, with a slope angle of more than 70 degrees.

![Figure 5. Slope geometry and landslide stratigraphic characteristics](image_url)
Based on the elevation data obtained from the study, the slope geometry of the study area can be redesigned as in Fig. 5. The slope geometry of the landslide field is curved so that it can be categorized into rotational landslide types. After knowing the parameters of the landslide, the next step is to make the slope geometry in FEM. The geometry of the landslide in FEM is used to determine the prediction of slope compiler material before it is released and the prediction of the release of slope compiler material (landslide material).

3.2. Slope stability and evaluation
Reverse calculation of the slope case is performed to determine the safety factor of the slope based on the landslide mechanism using the slope geometry from topographic measurements. Field conditions are very steep so that soil samples taken with shallow depths only reach 2 m. This is caused by the layer of soil at the study site is very tenuous and easily eroded. In order to obtain the proper slope conditions, a redesign of the slope geometry is appropriate in the field (Fig. 6). This image is used to input geometry data into FEM, using alternative soil-rock test group data based on a combination of soil parameter predictions according to laboratory test results, and related references through the trial and error method approach to get the desired results according to the field.

![Figure 6. (a) Batu Gadjah Landslide (RT.003 / RW.01), (b) Sketch of the slide type geometry model (using model [6])](image)

To study these data, soil-rock groups such as soil density, cohesion and shear angles are used to model slope landslides according to reality on the ground. This study focuses on two prediction models, namely the influence of variations in groundwater table (GWT) in the dry season and in the wet season (rainy).

3.3. Slope Stability Evaluation Solution Method
To solve the slope evaluation problem the Fellenius method approach according to Zhang [10] is based on landslide conditions. To determine the slope safety factor (FS) used Fig. 3, where the Fellenius cutting method divides the slope into several slices [6,9,10], then using equilibrium moments, is produced:

$$ F_S = \frac{\sum_{i=1}^{n} [c_i + (W_i \cos \beta_i - u) \tan \phi_i] \ell_i}{\sum_{i=1}^{n} (W_i \sin \beta_i)} $$

(4)

where $c_i$ and $\phi_i$ are the slope cohesion and internal friction angles, $W_i$ is the gravity weight of the sliced, and $\ell_i$ is the arc length of the sliced circle, $\beta_i$ is the angle between the tangent lines of the slice surface and the horizontal line.
3.3.1 Analytic solutions
Analytical solutions for slope landslides use the Fellenius method approach (Zhang [6]), to obtain a safety factor, $F_S$ as:

$$F_{S(i)} = \frac{c[L] + \{\gamma[N] - u[L]\}\tan \phi}{\gamma[T]}$$

(5)

where $\gamma$ is the weight of soil content, $\phi$ is the angle of deep friction, and $c$ is cohesion.

3.3.2 Numeric solution
By not using landslide assumptions, FEM can be used to determine slope safety factors. $F_S$ is obtained by increasing or decreasing the value of cohesion and apparent shear angle, gradually until the soil rock layer experiences landslides. Automatic $F_S$ values are obtained using FEM as in equation (2). The FEM approach for determining the factor of safety of slopes has satisfied the criteria for effective computer-aided analysis. The widespread use of this method should now be seriously considered by geotechnical practitioners as a more powerful alternative to traditional limit equilibrium methods [14].

3.3.3 Evaluate slope stability before landslides
The slope geometry before the landslide is redesigned based on the geometry of the landslide in the field. The results of slope geometry measurements before landslides are entered into analytical and numerical solutions to evaluate slope stability conditions before landslides based on $F_S$. $F_S$ is obtained from analytical solutions and FEM is shown in Fig. (7-8), and Table 1. Slide plane obtained with FEM in non-rain conditions and GWT are far from the surface of the parcel, hence the safety factor, $F_S = 1.10$ (Fig.7). $F_S$ obtained exceed 1.10, indicating that the slope conditions are critical. The $F_S$ ratio obtained from FEM solution and analytical solution is 6.8% for dry conditions (no rain has occurred yet).

| Landslide Location       | Slope safety factor ($F_S$) |
|--------------------------|-----------------------------|
| Batu Gadjah              |                             |
| (RT.03/RW.01)            | Analytic: 1.18              |
|                         | FEM: 1.10                   |

Figure 7. Sliding surfaces on slopes in dry conditions
3.3.4 Evaluation of slope stability after a landslide

The issue of slope stability at the study site after a landslide was re-evaluated. The results of the calculation of the slope safety factor ($F_s$) are shown in Table 2. The influence of ground water is very significant on the slope landslide process at the study site. The calculation results show that rising groundwater level on the slopes can reduce $F_s$ (Fig. 9).

| Landslide Location       | Slope safety factor ($F_s$) |
|--------------------------|-----------------------------|
| Batu Gadjah (RT.03/RW.01)| 0.99                        |
|                          | 0.90                        |

Table 2. Factors for post slide safety

Figure 8. Graph of slope safety factors before landslides ($F_s = 1.10$)

Figure 9. Sliding plane on a slope with a water table in wet conditions
The sliding plane indicates the type of landslide is a rotational slide. These landslides are affected by groundwater and slope geometry, which triggers slope instability. When compared with the FS results calculated by FEM and analytical methods, the results obtained are close to 9.1% for slope conditions in dry conditions. Considering an FS value close to 1.07 (as stated by [15-17]), if the ground water level rises with the assumption that there is rain which results in soil conditions becoming more saturated with FS < 1.07 (Fig. 10) resulting in the occurrence Avalanche. The slope cover soil layer that experienced a landslide is in layer 1, which is a layer that has experienced weathering, while in layer 2 the shape is slightly changed and layer 3 does not change shape. Slopes in wet conditions, greatly affect the strength of the soil, pore pressure can increase the deformation that occurs when receiving a load, when compared to slopes in dry conditions. The existence of pore pressure will reduce the effective strength of the soil such as internal friction angles, cohesion and modulus of deformation from the soil. In this simulation, the presence of ground water greatly affects the underside of the slope.

The results of the calculation of safety factors (Fs) at the study site have an impact when the greater the slope geometry, the lower the Fs value. As stated by [6], that the slope is dangerous if the value of the safety factor is low. If FS = 1.07 causes the slope to be unstable / critical. As such, the study area is thought to be in a critical condition and has the potential for subsequent landslides if triggered by natural and non-natural factors.

4. Conclusion
   a. Based on the results of calculations using analytic and numerical (FEM), the value of the slope safety factor > 1.07 for dry slopes, and after the wet slope the safety factor value < 1.07 indicates that the study area has experienced a landslide.
   b. To minimize the occurrence of aftershocks, prevention is needed by using the water toll model that is integrated with the biotechnology and geoforestry models.

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