Slope stability analysis using bishop method and kinematic analysis

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Abstract. Mining activity, especially open-pit mining, has caused an effect on the nearby environment. One of the most visible impacts caused by mining activity is the change in the nearby landscape. Steep slopes are common in open-pit mining area, thus the chance of landslides happening is high. To determine areas that are prone to landslides, the analysis of slope stability in the mining area is deemed necessary. “Bishop” methodology is used to determine the safety factor (SF) with the aid of “Rocscience Slide” software using “Mohr-Coulomb” strength type, with weight, cohesion, and friction angle as units in the parameter. And then a kinematic analysis is done by Stereonet projection in “Dips” software to determine the type of landslide. The safety factor value gained from the calculation is 1.112, and then after the treatment of slopes has been done, the safety factor value increases to 1.772, when referring to the bowless classification, which SF value> 1.25, it can be said that this slope is in a stable condition. After kinematic analysis had been done the type of landslide determined is “Wedge”. So it can be concluded that the slope on the east side of the pit is not safe, with a possibility of a Wedge type landslide occurring. But by changing its geometry we can produce a Safety Factor value that is considered safe.

1. Introduction
To guarantee safety in mining activity, information or data about stability of the slope is needed. To find out the condition of the slope, analysis needs to be done on the slope stability to determine if the slope is safe or not. The purposes of this research is to determine the type of landslide that can happen, recommended the action to take and make a slope design based on Bishop Method. In this case, study on the soil and rocks is necessary, whether it be on the field or in the laboratory to determine each physical and mechanical properties, orientation of the joint, and also measurement of the slope geometry. Slopes are divided into two, namely natural slopes and artificial slopes, natural slopes are slopes formed due to the process geology, for example river cliffs and hillside. Artificial slope is a slope formed due to a pile and excavation process [1]. Slope body material can be formed by soil or rocks. The analysis methods of soil slope are different from the analysis of rock slope [2]. All of these parameter will be used to determine the slope condition. Factors that affect slope stability can produce shear strain on the soil mass, movement of the soil will happen, except if the shear stress on the surface crumbles, which caused by the shear strain value is larger than the shear stress [3].

Kinematic analysis is done by projecting the shear orientation and slope to the stereonet, which then can determine the type of landslide that can happen, safety factor value, and slope design using Bishop Method with the Mohr-Coulomb strength type.
The data required to determine the slope safety factor is slope geometry, soil or rock mechanics data that includes friction angle (ϕ), rock or soil mass (γ), cohesion value (c), groundwater content (ω) [4]. Slopes with critical or labile angles need to be further investigated with sufficient samples, and sampling methods through drilling, so that data at a certain depth can be obtained [5].

2. Methodology

2.1. Kinematic analysis

To determine the potential of landslide in a slope in this research, stereographical technique is used. The technique is a graphical method used to determine the strike and dip of a plane, and is commonly used for determining the type of landslide or rock collapsing. Plotting the plane’s strike and dip in conjunction with the discontinuity of a plane in a stereonet can determine the type of rock collapse.

In general, the combination of discontinuity orientation will form 4 types of landslide/slide failure on rocks, which is:

- (circular sliding failure),
- (plane sliding failure),
- (wadge sliding failure),
- (toppling failure).

To determine the possibility of landslide or slope failure on rock slope cutting activity, the orientation of the discontinuity needs to be mapped, before and after the slope has been exposed to the surface.

2.2. Bishop method

This method is basically the same as the Swedish Method, but its takes account the force between the existing slices. The bishop method assumes the landslide base as a circular shaped arc. First, the slope geometry and the center point of the circular arc, and the position of the shear needs to be known.

The bishop method commonly used in slope stability analysis because of the simple calculation and accurate calculation of the safety factor. This method is suitable for finding critical failure plane automatically to find the minimum value of safety factor. The bishop method calculates the vertical and horizontal forces by keeping track of the balance of each slices [6].

Formula for safety factor by barrier force moment.

\[ R \sum W \cdot \sin \alpha = \frac{R}{F} \sum sl \]  
\[ SF = \frac{\sum sl}{\sum W \cdot \sin \alpha} \]

The minimum safety factor with a critical circle can be produced by changing the center’s position. Water saturation in water or soil can produce lifting force because the decrease in normal force on the base of the slice, so the slope stability analysis must be conducted on its effective stress condition.

On the bishop method, P (normal force on the base of the slice) is obtained by breaking down the forces working on the slice into down force (W) or into force resultant on the vertical slice limit in horizontal direction, to calculate the safety factor.
So that safety factor equation can be obtained, which is:

\[
SF = \frac{1}{\Sigma W \sin \alpha} \left[ \frac{(c \cdot b + (w - b \cdot u) \tan \phi \sec \alpha)}{1 + \tan \phi \tan \alpha / F} \right] \tag{3}
\]

\[
SF = \frac{\Sigma [c \cdot b + (w - u \cdot b) \tan \phi] \left( \frac{1}{\cos \alpha (1 + \tan \phi \tan \alpha / F)} \right)}{\Sigma W \sin \alpha} \tag{4}
\]

\[
M_i = \cos \alpha \left( 1 + \tan \phi \tan \alpha / F \right) \tag{5}
\]

\[
SF = \frac{\Sigma [c \cdot b + (w - u \cdot b) \tan \phi] \left( \frac{1}{M_i} \right)}{\Sigma W \sin \alpha} \tag{6}
\]

Safety factor is reflect the slope conditions. In several studies on slope stability analysis, the SF value plays an important role in determining the meaning of slope stability. Based on several landslide events, from Bowles (1989) gives FS < 1.07 for the usual occurrence of slope collapse, 1.07 < FS <1.25 for slope collapse ever occurred, and FS > 1.25 for collapse events are rare.

3. Field condition

3.1. Geological condition

Bramastya et al have conducted a geological study at the Pemali Mine, Pemali District, Bangka Regency, Bangka Belitung Province [7]. Based on the geological map of Bramastya et al, the study area was arranged by Meta-claystone, coarse granite, medium granite, fine granite, and Fault Gouge. Structures in the mine area have also been identified as normal faults, reverse faults, thrust faults and strike faults [7].
3.2. **Slope condition**

The slope to be analyzed is the east side of the Pemali mine, which is the slope most often landslides. The rocks on this slope are composed of mica schist and granite interpreted by local geological map (figure 2).

![Figure 2. Slopes section line.](image)

![Figure 3. Geological section of slope.](image)

4. **Results**

4.1. **Analysis of slope stability**

After making the geological section, then the section is inserted into the Rock Science Slide 6.0 software to analyze its stability so that the safety factor and the center radius of the failure field are obtained by entering data in the form of slope length, slope height, cohesion value, unit weight, friction angle and method which is used, in this case is the bishop method.

![Figure 4. Actual slope safety factor.](image)
After the actual slope analysis is performed, the SF value obtained in the bishop method is 1.112 (Figure 4). So if according to bowless, this slope is included in the category of critical slopes, so it is necessary to correct the slope, which is to cut the critical slope with a berm length of 15m, and a single slope of 55°, so it is expected to increase the safety factor of the slope [8].

![Figure 5. Slope safety factor after changing geometry.](image)

After correcting the slope, an increase in SF value is obtained, which is obtained SF value at 1.772 (Figure 5), so according to bowless the slope is included in the safe category.

4.2. Kinematic analysis

Stereographic methods are used to help identify the types of collapse / sliding that might occur on a slope. Based on the data taken of the strike and dip of the discontinuity and the slope face, from a stereonet will be able to know the type and direction of the potential landslide. The stereographic analysis method (stereonet) is only used for rocks that have weak fields or areas of discontinuity like bedding, joints, fault, and so on [9].

Based on the patterns of discontinuity and slope position, there is a wedge sliding failure model formed by two sets of discontinuities (Figure 6), JS1 and JS2. Based on kinematic requirements for wedge sliding failure proposed by Hoek and Bray’s, where JS1 and JS2 form an intersection angle whose direction is not parallel to the slope direction [10]. Based on the kinematic requirements for the specified wedge slide failure type, it can be said that the sliding type that may occur on the study slope is a wedge slide failure.

![Figure 6. Kinematic analysis.](image)
5. Conclusion

From the research that has been done, it can be concluded:

- Slope Actual Safety Factor is 1.112, included in the unsafe category.
- Slope Safety Factor After Changing Geometry is 1.772 is included in the safe category.
- Landslide type by kinematic analysis is wedge slide failure.

References

[1] Terzaghi K 1925 *Theoritical Soil Mechanics for Civil and Mining Engineers* London: Granada
[2] Gunthew A and Thiel C 2009 Combined rock slope stability and shallow landslide susceptibility assessment of the Jasmund cliff area (Rugen Island, Germany) *Natural Hazards and Earth System Sciences* **9** 687–698
[3] Bowles B, Joseph E and Hainim Johan K 1991 *Sifat-Sifat Fisis dan Geoteknis Tanah (Mekanika Tanah), Second Edition* (Erlangga: Jakarta)
[4] Arief I 2016 *Geoteknik Tambang: Mewujudkan Produksi Tambang yang Berkelanjutan dengan Menjaga Kestabilan Lereng* (PT. Gramedia Pustaka Utama: Jakarta, Indonesia)
[5] Zakaria Z, Sophian I, Sabila Z S and Jihadi L H 2018 Slope Safety Factor and Its Relationship with Angle of Slope Gradient to Support Landslide Mitigation at Jatinangor Education Area, Sumedang, West Java, Indonesia, *IOP Conf. Series: Earth and Environmental Science* **145** 012052
[6] Bishop A W 1955 *The Use of Slip Surface in The Stability of Analysis Slopes* Geotechnique **5** London
[7] Bramastya K G, Setijadji L D and Yogatama A W 2018. *Structural Controls to Greisen Tin Deposits in Pemali Tin Mine, Proceeding*, Pekan Ilmiah Tahunan IAGI 2018
[8] Bowles J E 1989 Physical and geotechnical properties of soils,2nd edition, (McGraw-Hill Book Company : New York)
[9] Hudson J A 1997 *Engineering Rock Mechanics An Introduction to The Principles* (United Kingdom: Elsevier Science Ltd)
[10] Hoek E and Bray J 1981 *Rock Slope Engineering,3rd edn, Inst. Mining and Metallurgy* (London: UK)