Risk Analysis of Slope Stability Open Mine With Probability Method PT. Timah (Persero) TBK Batubesi Area, Damar, East Belitung

Teguh Samudera Paramesywara¹, Budhi Setiawan¹

¹Geological Engineering Study Program of Sriwijaya University
teguhrgb@gmail.com

Abstract. The stability of mining slopes, especially on tin minerals, has different criteria than other minerals. The safety factor that becomes the reference value of the stable slope of the mine can also reflect the movement of the land (Lubis, 2012 in Wijayanti, 2015). In processing these FK values often do not take into account that all parameters have equal opportunity to represent those parameters (Azizi, 2012). The probability method is a way of analyzing the risk of mining slopes by including several parameters including wet density, dry density, cohesi and friction angle. The research aims to get FK and PK values that are stable and efficient to be mined because the smaller than the slope is opened, the smaller the tin mineral recovery and the higher the stability of the slope and vice versa. To get the value of FK and PK need to do slope analysis with limit equilibrium method and probability method then modeled with Slide V.6.0 software and calculation with Excel program. Data processing is from 4 drill points found that GT_01 with value FK > 1.3 indicating that the slope safe and movement of soil can occur and get value PK 0.5 – 0.6 %. For GT_02, GT_03 and GT_04 obtained unsafe slope results so optimization is necessary.

1. Introduction
The need for tin minerals is increasing as the reduction of tin reserves in Indonesia has an impact on the economy. To meet market demand, PT. Timah (Persero) TBK which is a State Owned Enterprise (BUMN) opened several new mining PIT, one which is in the East Belitung area.

The opening of the new mining PIT requires geotechnical studies in planning, especially on the mine slopes. Safe mining slopes can minimize landslides, losses to companies and mining activities are not hampered.

Stability of the mine slope is a state of slopes that can be said to be safe or stable which is expressed in the index of safety factors (FK). The steeper the slope more unstable it increases the risk of slope safety or vice versa. Handling is necessary for this to achieve maximum mining again.

Currently, the factor of safety (FK) is not the only benchmark in assessing the safeness of a mine slope. Various ways and approaches have been done by geotechnical experts in solving this problem, one of them with a risk analysis approach that assesses the function of the likelihood of sliding (PK) and its impact [1][2].

The formulation of the problems and limitations in this study is to determine the quality of rock mass, the opening of the slope angle, the value of FK and PK that are safe and the optimal design of
the mine slope. Research conducted on open pit contained in Batubesi area, Damar District, East Belitung Regency, Bangka Belitung Islands Province.

This study aims to analyze the risk of mining slope expressed in the form of factor safety (FK) and probability of sliding (PK). FK is calculated using the limit equilibrium method which is assisted with software Slide V.6.0 and PK assisted microsoft excel to simplify the calculation.

2. Data and Method

To get a slope design that is far from risk it is necessary to know the uncertainty in the slope stability shown on Table 1.

Table 1. Source of uncertainty of the slope [1]

| Aspect of the slope     | Uncertain Sources                             |
|------------------------|-----------------------------------------------|
| Geometry               | Topography, geology/structure, groundwater    |
| Characteristics        | Strong shear, deformation, hydraulic conductivity |
| Loads (Tester Style)   | Insitu voltage, blasting, earthquake          |
| Prediction Avalanche   | Model reliability                             |

To get the FK it is necessary to know the physical properties of mechanical rocks that become the constituent components of the slope shown in Table 2.

Table 2. Distribution of input parameter values

| Lithology               | Parameter Statistik | Y\text{dry} (kN/m^3) | Y\text{sat} (kN/m^3) | C (Kpa) | \phi   |
|-------------------------|---------------------|-----------------------|----------------------|---------|--------|
| Unconsolidated Material | Minimum             | 1.97                  | 2.21                 |         |        |
|                         | Maksimum            | 2                     | 2.23                 |         |        |
|                         | Average             | 1.985                 | 2.22                 | 54      | 21.25  |
|                         | Std. Deviasi        | 0.02121               | 0.01414              |         |        |
| Top Soil                | Minimum             | 1.97                  | 2.23                 | 74      | 22.31  |
|                         | Maksimum            | 2.09                  | 2.28                 | 120     | 22.77  |
|                         | Average             | 2.0275                | 2.24375              | 83,429  | 21,0443|
|                         | Std. Deviasi        | 0.03173               | 0.02363              | 21,625  | 1.61152|
| Oxide Clay              | Minimum             | 1.98                  | 2.21                 | 50      | 17.69  |
|                         | Maksimum            | 2.09                  | 2.28                 | 120     | 22.77  |
|                         | Average             | 2.0273                | 2.24364              | 83,429  | 21,0443|
|                         | Std. Deviasi        | 0.03003               | 0.0169               | 1945.2  | 789.422|
| Skarn                   | Minimum             | 2.23                  | 2.4                  | 210     | 26     |
|                         | Maksimum            | 2.34                  | 2.45                 | 4230    | 44.59  |
|                         | Average             | 2.28273               | 2.42364              | 1810    | 37.425 |
|                         | Std. Deviasi        | 0.03003               | 0.0169               | 1945.2  | 789.422|
| Greisen                | Minimum             | 1.83                  | 2.13                 | 30      | 17.58  |
|                         | Maksimum            | 2.03                  | 2.2                  | 60      | 22.38  |
|                         | Average             | 1.90444               | 2.15778              | 44,876  | 19,3775|

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The method used in this research are as follows:
1. FK approach with Limit Equilibrium Method
   Is a method in slope stability calculated using the force equilibrium or moment equilibrium, or both of which yields the output of a slope stability factor value.
2. Probabilistic Method Approach
   Is an explicit method of assessing an uncertainty expressed in terms of probability of susceptibility (PK) and can give high confidence results in slope optimization [1].

The steps in doing this research are shown in the figure 1.

![Research Flow Diagram](image)

**Figure 1.** Research flow diagram

There are 4 borehole points as shown in the figure 2.
3. Result and Discussion

3.1. FK Approach with Limit Equilibrium Method

The FK score becomes an assessment to assess a safe or not. To get the value of FK done calculation by using equilibrium method assisted with software Slide V.6.0 then seen the relationship between movement of land to FK in accordance with tin mining. If the findings of less favorable FK, then done redesign shown as Table 3 and 4.

Table 3. The relationship between the value of the safety factor and the movement of the land [3]

| F     | Description                                      |
|-------|--------------------------------------------------|
| < 1,2 | High vulnerability, high probability for land movement |
| 1,2 - 1,7 | Medium vulnerability, ground movement may occur |
| 1,7 - 2 | Low vulnerability, soil motion can occur          |
| > 2   | Low susceptibility, rare earth movement or ground motion is almost unheard |

Based on tables 3 and 4 it can be seen that GT_01 get FK > 1,3 means a safe slope with ground motion can occur. Another case with GT_02, GT_03 and GT_04 whose slopes are not safe so it needs to do redesign in order to obtain a safe FK value. GT_02 get FK > 1,27 and GT_03 get FK > 1,3 indicates that the slope is safe with ground movement can occur. GT_04 get a FK value > 1,7 means a safe slope with low movement may occur.
3.2. Probabilistic Method Approach

Some probabilistic methods that can be used in determining the probability of slope (PK) are point estimate methods, hyperlatin cube methods and monte carlo simulations. This study used monte carlo simulations because many variations of FK values are assumed. In facilitating the calculation of The PK value of the slope it is assisted by using the excel program. In analyzing the PK results obtained by looking at the type of slope and the threeshold allowed to be used as a reference in the slope design described in the Table 5.

In this study, the slope used is the overall slope. In get PK results for GT_01 of the 0,5 – 0,6%. Whereas for GT_02, GT_03 and GT_04 after being redesign, the PK value is 1,5 – 1,6%, 0,5 – 0,7% and 0 – 0,2% respectively. So it can be said that the PK value is still within reasonable limits as shown by the Table 6.

![Table 4. Geometry eksisting and redesign](image)

| Slope Conditions | Bore Hole | Geometry | Unsaturated | Saturated |
|------------------|-----------|----------|-------------|-----------|
|                  |           | High Slopes (m) | Angle of the Overall slope (°) | Deterministic FK | Average FK | Deterministic FK | Average FK |
| Eksisting        | GT_01     | 57.6     | 40          | 1.36       | 1.4       | 1.3           | 1.38       |
|                  | GT_02     | 47       | 43          | 0.88       | 1.27      | 0.85          | 1.21       |
|                  | GT_03     | 65       | 40          | 0.78       | 1.2       | 0.75          | 1          |
|                  | GT_04     | 70       | 53          | 0.68       | 0.7       | 0.65          | 0.67       |
| Redesign         | GT_02     | 47       | 35          | 1.27       | 1.3       | 1.33          | 1.4        |
|                  | GT_03     | 50       | 30          | 1.3        | 1.36      | 1.28          | 1.34       |
|                  | GT_04     | 60       | 33          | 1.71       | 1.8       | 1.68          | 1.76       |

![Table 5. Threshold of FK value and PK of Open Mine Slopes (SRK, 2010 in Azizi, 2012)](image)

| Type of slope | Impact of avalanches | FK (min) Statik | FK (min) Dinamik | PK (Max) P[FK<1] |
|---------------|----------------------|-----------------|------------------|-----------------|
| Overall       | Low                  | 1.2 - 1.3       | 1                | 15 - 20%        |
|               | Medium               | 1.3             | 1.05             | 5 - 10%         |
|               | High                 | 1.5             | 1.1              | ≤ 3%            |

![Table 6. Output Analysis of Failure Safety and Probability Factors](image)

| Slope Conditions | Bore Hole | Unsaturated | Saturated |
|------------------|-----------|-------------|-----------|
|                  |           | Deterministic FK | Average FK | PK (%) | Deterministic FK | Average FK | PK (%) |
| Eksisting        | GT_01     | 1.36         | 1.4       | 0.5    | 1.3           | 1.38       | 0.6    |
|                  | GT_02     | 0.88         | 1.27      | -      | 0.85          | 1.21       | -      |
|                  | GT_03     | 0.78         | 1.2       | -      | 0.75          | 1          | -      |
|                  | GT_04     | 0.68         | 0.7       | -      | 0.65          | 0.67       | -      |
| Redesign         | GT_02     | 1.27         | 1.3       | 1.5    | 1.33          | 1.4        | 1.6    |
|                  | GT_03     | 1.3          | 1.36      | 0.5    | 1.28          | 1.34       | 0.7    |
|                  | GT_04     | 1.71         | 1.8       | 0      | 1.68          | 1.76       | 0      |

The slope design model using simplified bishop with saturated and unsaturated condition on all four drill holes as illustrated in the figure 3(A-C) and figure 4 (A-C).
4. Conclusion

Based on this research it can be concluded that: Uncertainty is a certainty that will occur later so that we can only predict then can minimize the impact, one of which can be done by planning in mining activities. In analyzing the risk of slope stability can be done by approaching the value of the safety factor (FK) and the probability value of slope (PK) with the probabilistic method. The calculation results show that GT_01 can be said safe with the value of FK > 1.3 and PK 0.5 - 0.6% is considered reasonable and not exceeded the specified limits. Another case with GT_02, GT_03 and GT_04 need to be done redesign to get the value of safe FK then conducted PK calculations. After a redesign was found that GT_02 with FK > 1.27 and PK amounted to 1.5 – 1.6%, GT_03 with FK values of more than 1.3 and PK 0.5 – 0.7% and GT_04 with FK values of more than 1.7 and PK is 0 - 0.2%. Based on this for GT_02, GT_03 and GT_04 after redesign can be concluded safe and still within the permissible limits. The analysis using this limit equilibrium method has weaknesses so it needs to combine with finite element method and back analysis to get a more accurate value.

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