The Analysis of The Slope Stability Design on Pemali, North Bangka, Bangka Belitung Islands, Indonesia

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Abstract

Geotechnical study is important in open-pit mining, especially for the determination of slope stability design. The object of this research is a tin open-pit mine which located in Pemali, North Bangka, Bangka Belitung Islands, Indonesia. This research was conducted because the safety factor of the actual slope in Pemali open-pit is below 1,2, which means critical. This is caused by the lack of material strength because of the strong weathering process. The purpose of this research is to redesign the slope in Pemali open-pit to obtain a stable safety factor value. The fieldwork consists of measuring slope geometry, soil mechanics properties, and disturbed soil sampling. Triaxial test and direct shear test are also carried out onto samples. Then, redesign the slope geometry and compute the safety factor value. The results of the slope stability analysis using simplified Bishop method shows that the actual slope must be changed to obtain the safety factor value above 1,2. The 25° actual overall slope must be changed to 15° on GT4, 15° on GT5 and 20° on GT6. Then the 60° actual bench slope must be changed to 45° on GT4 and 55° on GT6.

Keywords: slope stability, safety factor, geotechnics, Pemali

1. Introduction

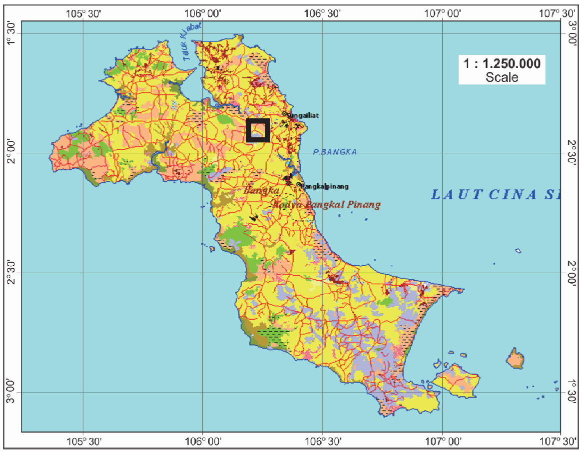

Fig. 1 Research Location. Pemali Mining Area, North Bangka, Bangka Island, Indonesia (black square).

The research is located in Pemali mining area, North Bangka, Bangka Island, Indonesia. The Pemali tin mine has existed since decades ago, and left for a dozen years. In 2012, the mining area is reopened for production (Sujitno, 1990). Therefore, mine slope review, analysis and investigation is needed because there is a significant difference in the material condition in the mine area, in order to avoid the slope failure that reduces the effectiveness of the mining activities.

Nowadays, the research area, which is the area of tin mine that have been abandoned for a dozen years, consist of not solid material or very weathered material and very steep slopes that makes mine slope getting slides in some places. Due to the mining reclamation, the slope should be recalculated in order to avoid the risk of mining disaster.

2. Methodology

This research is divided into two phase. The first phase is field measurement and the second phase is studio processing. The field measuring data are consist of slope geometry (length, height and slope) and soil mechanic properties (angle of internal friction, cohesion, water content and weight per volume). Triaxial test and direct shear test are also carried out onto samples. The field measurement data then processed into a geotechnical zone map based on geotechnical characteristic in the research area (Figure 3).

The last phase is slope simulation in order to obtain the slope with the biggest safety factor value. Bishop's safety factor method is carried out in the slope simulation because in Arief (2007), Bishop's simplified method is the most often used in slope stability analysis. Several assumptions were made in simplified Bishop method (Bishop, 1955; Anderson and Richards, 1987):

1. The failure is assumed to occur by rotation of a mass of soil on a circular slip surface centered on a common point.
2. The forces on the sides of the slice are assumed to be horizontal. Thus, there is no shear stress between slices.
3. The total normal force is assumed to act at the center of the base of each slice.

Although, simplified Bishop method does not satisfy equilibrium, but safety factors derived from this method is in agreement with the safety factors calculated from finite element methods (Wright et al., 1973). The value of safety factor in Bishop's method is formulated as follows:

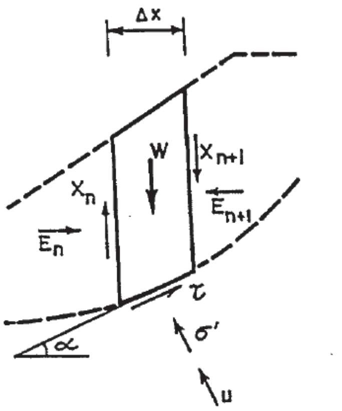

Fig. 2 Stresses and Forces Acting on a Typical Slices.

$$F = \frac{\sum (c' \Delta x \sec \alpha + N' \tan \phi)}{\sum W \sin \alpha} \quad (1)$$

Where

c' : Cohesion
Δx : Slice Width
W : Weight of Slice
N' : N – U
N : W cos α
U : Pore Pressure Force
α : Slice base inclination
Φ : Friction Angle

3. Results and Discussion

Lithology characteristic, angle of internal friction, cohesion, water content and weight per volume data is obtained from the field measurement that carried out by Timah Ltd. Company (some data not attached in this paper due to the company copyright). The data then processed into a geotechnical zone map (Figure 3).

In the geotechnical zone map, there are three zones, and each of them has a different characteristic. Zone 1 consists of kaolin has a white coloured, and strongly weathered. The soil derived from the weathering of kaolin, feldspar, and less quartz. The soil physical properties are low toughness, moist, and low plasticity.

Zone 2 consists of claystone, derived from strongly weathered metasedimentary rock, has a brown coloured, low toughness, moist, and medium plasticity. Below this material, there is a purple coloured claystone from weathered phyllite, less quartz, soft, moist, and high plasticity. In this zone, the weathered material that oxidized and has a reddish colour can be found. Weathering process will be reduced when the material is getting deeper.

The lithology in zone 3 is intrusion of granite that formed into sandstone and claystone with some gravels because of the weathering process. Have a low toughness, low plasticity, and moderately moist.

Fig. 3 Geotechnical Zone Map of Research Area

The actual mine slope in Pemali mining area has certain standards and identical on all sides. The slopes are 25° in overall slope and 60° in bench slope. Then the slope redesign refers to the drilling data

Table 1 Calculations Result of Safety Factor Value on GT4

No. Site	GT4																			
Angle of Overall Slope	30					25					20					15				
FS	0,749					0,764					0,852					1,306				
Angle of Bench Slope	40	45	50	55	60	40	45	50	55	60	40	45	50	55	60	40	45	50	55	60
FS	0,885	0,883	0,882	0,885	0,864	1,028	1,025	1,018	0,984	0,869	1,189	1,189	1,161	1,198	0,984	1,583	1,581	1,106	1,004	0,818

Table 2 Calculations Result of Safety Factor Value on GT5

No. Site	GT5																			
Angle of Overall Slope	30					25					20					15				
FS	0,663					0,825					0,951					1,309				
Angle of Bench Slope	40	45	50	55	60	40	45	50	55	60	40	45	50	55	60	40	45	50	55	60
FS	0,902	0,904	0,904	0,905	0,898	1,043	1,042	1,043	1,042	1,044	1,280	1,275	1,272	1,229	1,128	1,605	1,608	1,607	1,233	1,223

Table 3 Calculations Result of Safety Factor Value on GT6

No. Site	GT6																			
Angle of Overall Slope	30					25					20					15				
FS	0,785					0,997					1,165					1,446				
Angle of Bench Slope	40	45	50	55	60	40	45	50	55	60	40	45	50	55	60	40	45	50	55	60
FS	1,102	1,335	1,309	1,084	1,079	1,431	1,253	1,251	1,249	1,027	1,602	1,494	1,481	1,220	1,060	1,971	1,935	1,904	1,096	1,035

from GT4, GT5 and GT6 borehole by changing the slope into several slope with a certain interval to obtain the slope with the highest safety factor value. The slope simulations use 5° interval from 15° to 30° in overall slope and 5° interval from 40° to 60° in bench slope (Table 1, 2, and 3).

In GT4, from surface to 45 meters below the surface, consist of brown topsoil with metamorphic gravel which has a value of density 16,474 kN/m³, cohesion value 15,690 kN/m², and angle of internal friction 12,5°. Yellow clay with quartz and feldspar which has a value of density 18,435 kN/m³, cohesion value 6,276 kN/m², and angle of internal friction 18,22°. Weathered phyllite which has a value of density 18,239 kN/m³, cohesion value 15,690 kN/m², and angle of internal friction 19,5°. Sandstone which has a value of density 18,141 kN/m³, cohesion value 12,846 kN/m², and angle of internal friction 19,85°. Weathered hornfels which has a value of density 18,141 kN/m³, cohesion value 26,084 kN/m², and angle of internal friction 28,5°. And mixing clay with gravel which has a value of density 17,651 kN/m³, cohesion value 36,282 kN/m², and angle of internal friction 21,9°.

In GT5, from surface to 48 meters below the surface, consist of brown topsoil which has a value of density 19,416 kN/m³, cohesion value 3,530 kN/m², and angle of internal friction 9,66°. Clay with gravel which has a value of density 18,828 kN/m³, cohesion value 29,320 kN/m², and angle of internal friction 26,51°. Sandstone with gravel of metamorphic rock weathering which has a value of density 18,926 kN/m³, cohesion value 22,456 kN/m², and angle of internal friction 20,12°. Weathered kaolinite which has a value of density 19,318 kN/m³, cohesion value 6,766 kN/m², and angle of internal friction 29,55°. Weathered schist which has a value of density 18,337 kN/m³, cohesion value 13,826 kN/m², and angle of internal friction 17,42°. And weathered granite which has a value of density 18,239 kN/m³, cohesion value 9,512 kN/m², and angle of internal friction 23,15°.

In GT6, from surface to 54 meters below surface, consist of reddish brown topsoil which has a value of density 18,886 kN/m³, cohesion value 9,904 kN/m², and angle of internal friction 23,76°. Sandstone with clay which has a value of density 19,024 kN/m³, cohesion value 8,531 kN/m², and angle of internal friction 28,25°. Sandstone with gravel which has a value of density 20,210 kN/m³, cohesion value 18,631 kN/m², and angle of internal friction 28°. Very weathered phyllite which has a value of density 19,230 kN/m³, cohesion value 15,199 kN/m², and angle of internal friction 25,38°. And weathered granite which has a value of density 19,230 kN/m³, cohesion value 12,552 kN/m², and angle of internal friction 22,02°.

The safety limit of safety factor value is based on the safety factor value classification by Ward (1976). Because the area has a loose and very weathered material, landslide is possible to occur in mine slope if the safety factor value below 1,2 and it could be critical (Table 4).

The result of the simulations are the actual mine slope's safety factor value is below 1,2. Those are 0,869 on GT4, 1,044 on GT5 and 1,027 on GT6. Therefore the actual overall and bench slope must be changed to obtain the safety factor value above 1,2.

Table 4 Ward Classification of Relation Between Safety Factor and Ground Movement (Lubis, 2012)

F	Information
< 1,2	High vulnerability, it would be high possibility for ground movement.
1,2 – 1,7	Medium vulnerability, ground movements can occur.
1,7 – 2	Low vulnerability, ground movements can occur.
2 <	Low vulnerability, rare ground movements or ground movements almost never occur.

The actual slope must be changed to 15° in overall slope and 45° in bench slope to obtain 1,581 safety factor value on GT4. Then on GT5 the actual slope must be changed to 15° in overall slope and 60° in bench slope to obtain 1,223 safety factor value.

Furthermore the actual slope must be changed to 25° in overall and 55° in bench slope to obtain 1,249 safety factor value on GT6.

4. Conclusion

The result shows that the actual mine slope has 0,869 safety factor value in GT4 slope, 1,044 in GT5 slope and 1,027 in GT6 slope. It means the actual mine slope is critical, because the safety factor value is below 1,2.

Afterwards, the slope simulations is carried out by simulating the slopes with a certain interval and slope conditions. According to the simulations, to obtain the safety factor value above 1,2, the 25° actual overall slope must be changed to 15° on GT4, 15° on GT5 and 25° on GT6. Then the 60° actual bench slope must be changed to 45° on GT4 and 55° on GT6.

The changes in value of the mine slope based on simulation will reduce the risk of landslide and will stabilize the mine slope. Thus, mining activities will run more effectively and productively.

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