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# Risk Evaluations for Stope Mining Affected by Slope Surface

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**Abstract**

This study describes the importance on the evaluation of rock mass condition before mining and probability of failure during mining under slope surface in shallow depth. It is well known that several factors can affect the stability of underground openings such as the quality of rock mass, the in-situ stress, the depth below the surface and opening geometry. In addition to those parameters, if underground mining is conducted near the slope surface, the influence of slope surface should be taken into account during any mining activities. Consequently, stability analysis has been conducted for three different conditions including the evaluation on the strength of rock mass in the sloping surface, assessment on the stability of stope mining near the slope surface, and instability of stope in the near-ground region in various mine condition. The preliminary results show the instability of rock mass near to slope surface is more severe than that of the rock mass far from the slope surface, therefore large instabilities of rock mass near the slope surface are experienced. In addition, the occurrence of failure zones of stope mining in the near-ground region under slope surface become more pronounced in weaker geological condition and higher stress ratio. All the investigations for these analyses are conducted by means of 3D finite difference software using FLAC$^{3D}$.

**Keywords**: Instability, Risk evaluation, Slope surface, Stope mining

## 1. Introduction

Stope mining is the most common mining method adopted in underground metal mines of Myanmar. However, the assessments on the stability of stope still remain quite limited in those mining industries. Currently, most of the underground metal mines are being mined-out or still mining at shallow ground part. Moreover, there are not so many recorded data regarding rock mass failures cases in underground mining due to cut and fill stoping methods in Myanmar. Hence, the study on the stability of underground mines in shallow part become one of the important issues to mitigate the unpredictable nature of rock failures. Two forms of instability are readily observed around underground openings: (1) structurally controlled gravity-driven processes (2) stress-induced failure or yielding (Martin et al. 2003). In many pieces of literatures, some instability indicators are usually defined in terms of failure zones, stress condition, displacement and extent of yield zones (Abdellah et al. 2018) (Karian 2016) (Purwanto et al. 2013). In this study, the evaluation on rock mass condition and mining under the sloping surface are described by the occurrence of natural and mining-induced differential stress and failure zones affected to mining activities. Considering the importance stability of underground mining under slope surface, some investigations on the characteristics of rock mass and mining condition are carried out at Modi Taung gold mine, one of the largest underground gold mines in Myanmar.

## 2. Methodology

The evaluation on the rock mass condition before mining and probability of failure during mining under slope surface in shallow depth is investigated by using FLAC$^{3D}$ software, which is used for stress and deformation analyses around the surface and underground structure (Itasca Consulting Group Inc. 2012). In this study, the size of the basic numerical model is 260 m × 260 m × 320 m with vein dip 70 degrees as shown in Fig. **1**(A). As the slaty mudstone is a dominant rock type in Modi Taung gold mine (Mitchell et al. 2004), the hanging wall and footwall are assigned as a homogenous model for simplification. In the simulation, the Mohr-Coulomb failure criterion is adopted and all mechanical properties of rock used in this study are shown in Table 1. The stoping sequence in mining area takes place from the lower slice to upwards direction and the dimension of the stope is 2.5 m in height and 2 m in width. The waste rocks from the excavation are only used to both fill the stope and provide permanent wall support for the lower mine-out cavity.

The contents of numerical analyses are divided into three parts in this study. Firstly, in order to understand the strength of rock mass near the slope surface, the simulation is carried out with a basic numerical model. Various monitoring points of differential stress (the difference between major and minor in plane principal stresses, σ1 – σ3) subjected to the rock mass are recorded as shown in Fig. **1**(B). Secondly, the assessments on the stability of stope mining near the slope surface are investigated as shown in Fig. **2** (A) and failure zones are recorded at three cutting planes as shown in Fig. **2**(B). When the stope mining is operated in the near-ground part, it results in higher differential stress and higher risk of stope failure than that in the deeper part. Because of varying depths of overburden, mining activities along the sloping surface may experience different instabilities of the rock mass. Lastly, the instabilities of stope in the near-ground part under the sloping surface are examined in various mine condition including the variation of rock mass properties and different stress ratio. Uncertainties on the estimation of rock mass properties and in-situ stress distribution have a significant impact on the stability of underground excavations.

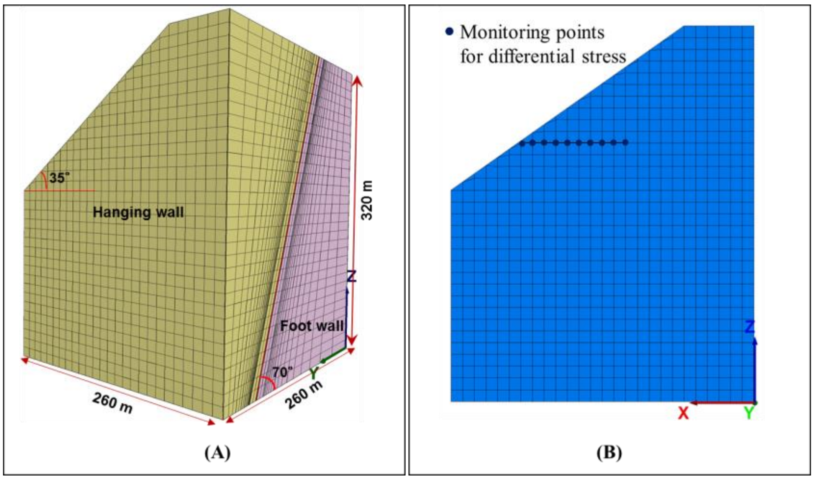


Fig. 1. (A) Basic model for this research, (B) Monitoring points for differential stress under slope.

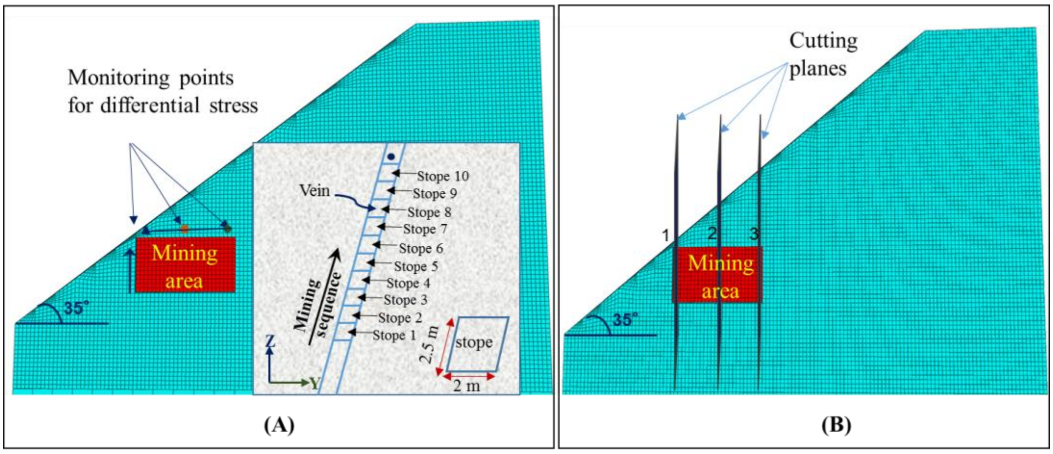


Fig. 2. (A) Stope mining under slope surface, (B) Cutting planes recorded for failure zone.

Table 1 Rock mass properties used in numerical simulations.

| | $E$ [MPa] | $v$ [-] | $\sigma_t$ [MPa] | φ [deg] | $C$ [MPa] |
|---|---|---|---|---|---|
| Hanging wall | 3786 | 0.23 | 0.035 | 44 | 0.761 |
| Foot wall | 3786 | 0.25 | 0.065 | 40 | 0.687 |
| Vein | 3786 | 0.22 | 0.034 | 45 | 0.77 |
| Filling rock | 153.1 | 0.321 | - | 20.5 | 0.200 |

## 3. Results and Discussions

### 3.1 Evaluation on the strength of rock mass under sloping surface

Monitoring is an important aspect of the design process. Uncertainty and risk have always been associated with mining activities. In addition, rock mass under sloping surface may experience unequal stress due to the weight of overlaying rocks. Because of unequal differential stresses acting on surrounding rock mass, the instability arises and failure can develop. For this sense, evaluation on the condition of rock mass under slope surface are conducted before any excavation. As shown in Fig. **3**(A), even though the most unstable part of the rock mass is experienced at the slope foot, the instabilities are gradually propagated to the inner part of rock mass from the slope surface. This result is demonstrated in Fig. **3**(B) that shows the illustration of differential stresses measured in sloping surface. It can be seen that the differential stresses are progressively increased from the inner part of the rock mass to the slope surface. That trend indicates that the stability of rock mass near the slope surface can meet more severe than that of the places far from the slope surface. Therefore, it should be noted that the mining activities near the slope should be paid attention to avoid unexpected rock mass failure.

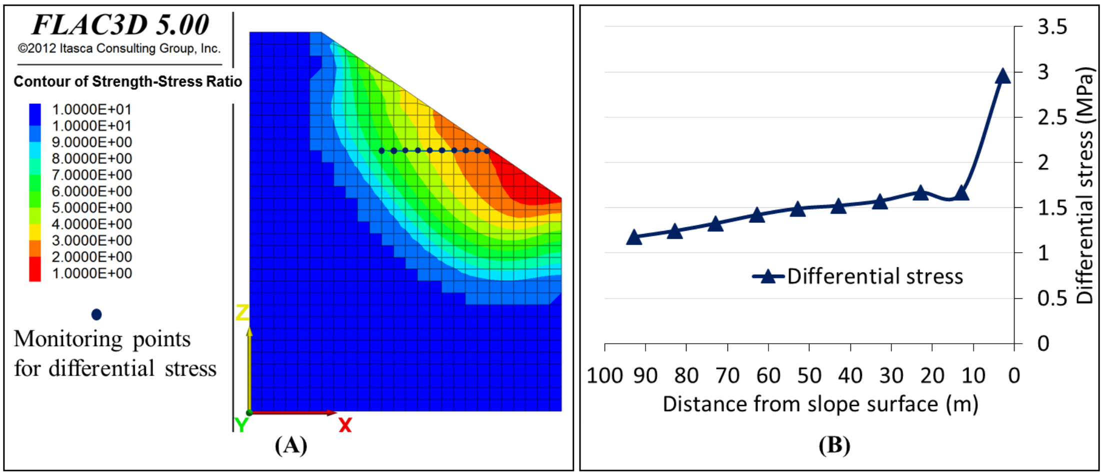


Fig. 3. (A) Rock mass condition under slope surface, (B) Differential stress measured under slope surface.

### 3.2 Evaluation on the stability of stope mining near the sloping surface

The condition of stope mining under the slope surface and stoping sequence is shown in previous Fig. **2** (A). When the stope mining is operated in the near-ground part under slope surface, the variation of stress and failure of the stope is affected more than the deeper part. Because of varying depths of overburden, mining activities along the sloping surface may experience different instabilities of rock mass based on the distance from the slope surface. Thus, three monitoring points for induced differential stresses were recorded at 3.5 m, 26.5 m and 49.5 m distance from slope surface. The results are shown in Fig. 4. All of these monitoring points are placed at 1 m above the final stope during stope mining. According to the result, when the mining sequence is advancing towards the slope surface, the induced differential stress is gradually increased due to the accumulation and redistribution of stresses from the lower excavations. Moreover, it can be seen that the highest differential stresses are appeared in the nearest to slope surface compared to the other two places. That trend indicates that the instability of rock mass occurred in the nearest place to slope surface is more severe than that of the rock mass far from the slope surface because of not only from the stress accumulation but also the influence of slope surface. This statement can be proved in Fig. **5** that showed the propagation of failure zones occurred in the bound of stoping sequence under the slope surface. These results are collected at 3.5 m, 26.5 m and 49.5 m distance from the slope surface respectively as shown in Fig. **2**(B). According to results, the occurrence of failure zones is more propagated to the excavation near the slope surface. On the contrary, the mining activities far from the slope are likely affected by its own induced stress, therefore the failure zone only occur around the stope mining without propagating to the surrounding rock mass. By seeing induced differential stress and failure zone condition as shown in Fig. 4 and Fig. **5**, if the mining activities become closer to slope surface, the potential of stope failure become higher. Thus, large instabilities of rock mass near the slope surface are expected, accordingly the stability of rock mass need to be monitored in the stope cavity especially at the nearest part to the slope surface.

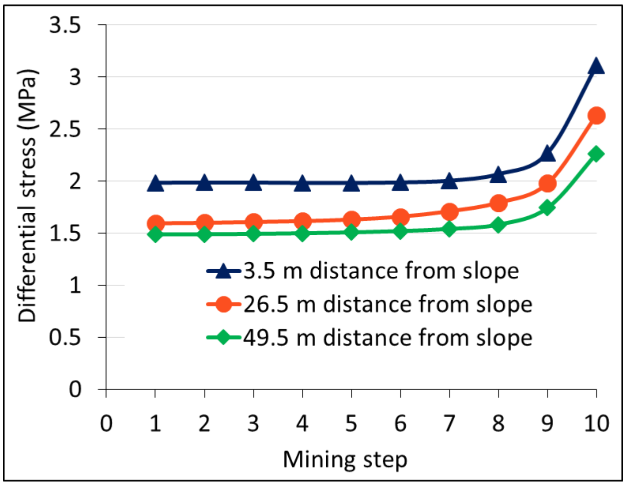


Fig. 4. Differential stress measured in the bound of stoping sequence under slope surface.

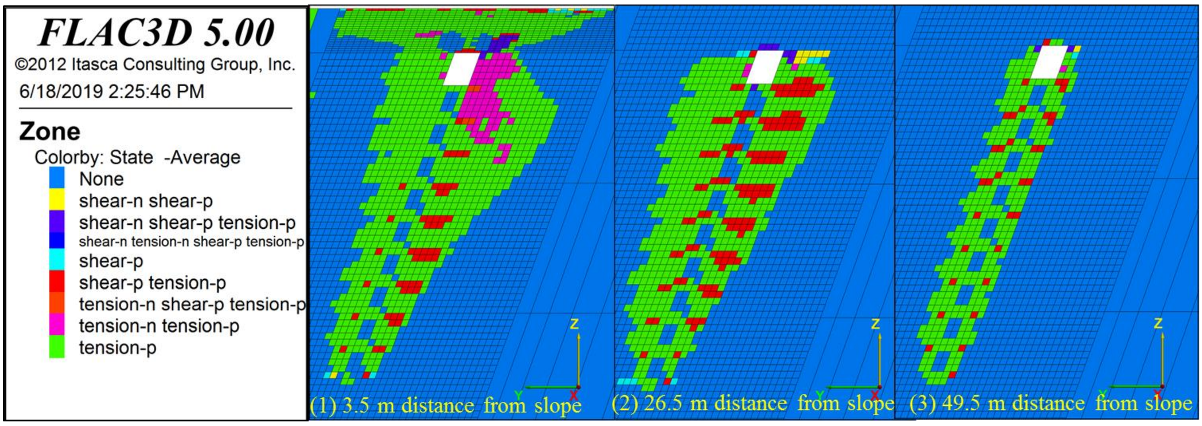


Fig. 5. Failure zones occurred in different places from slope surface.

### 3.3 Evaluation on the instability of stope in various mine conditions

Without a doubt, the strength of rock mass can differ from the variation of rock mass properties and the stress condition acting on that rock mass. Hence, the investigations on the stability of stope mining in the near-ground part under the slope surface are conducted on the variation of different rock mass properties and various stress ratio. As the most unstable region of stope cavity is the nearest part to the slope surface, accordingly the results from this part are recorded and discussed for various mine condition.

Firstly, investigations on different rock mass properties are carried out to understand the instability of stope mining under the slope surface due to the influence of different geological condition. Geological conditions are represented by Geological Strength Index (GSI) parameter (Marinos et al. 2005). In this study, numerical simulations are conducted with the various GSI numbers ranging from 39, representing blocky/disturbed/seamy rock mass folded with angular blocks formed by many intersecting discontinuity sets, to 49, representing very blocky rock mass with interlocked partially disturbed rock mass (Sonmez et al. 2004). The results of differential stress induced by stope mining near the slope surface are shown in Fig. 6. These results show that the higher the GSI number the lower differential stress. By seeing these results, it can be expected that the rock mass condition is more severe and the potential of stope failure might be experienced more in lower GSI than that of higher GSI. The result of this assumption can be found in Fig. **7** demonstrated the occurrence of failure zones in the different geological condition under the slope surface. Even though both of the tensile and shear failure occur in all rock mass properties, more severe conditions are experienced as the geological condition become worse.

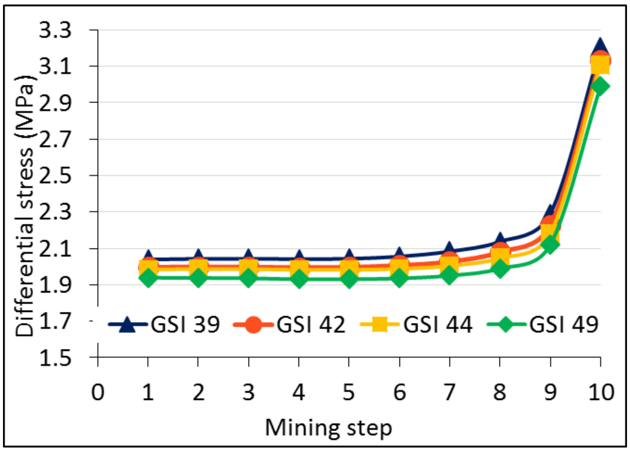


Fig. 6. Differential stresses measured in various geological condition.

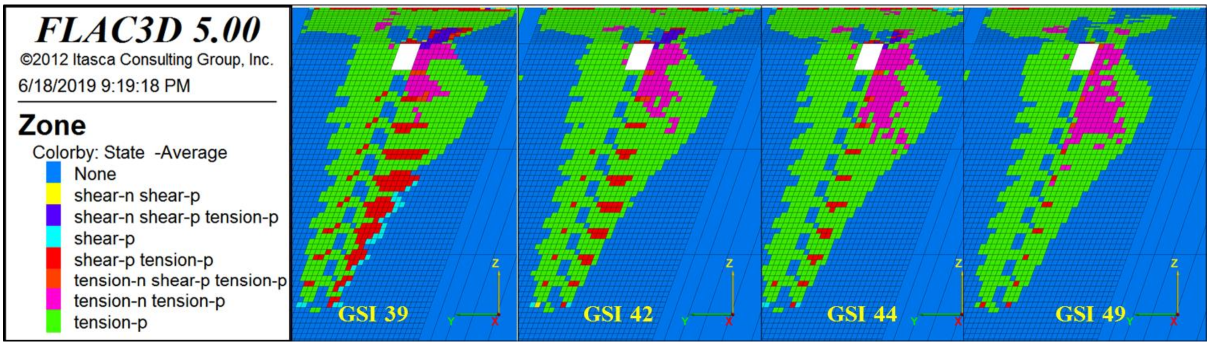


Fig. 7. Failure zones occurred in different geological condition.

Apart from the rock mass properties, another parameter that might influence the stability of underground excavation is the variation of in-situ stress. To assess this, the model with three stress ratios are simulated as a preliminary assessment of stope's instability under the sloping surface. Fig. **8** shows the condition of differential stress acting on rock mass and Fig. **9** indicates the occurrence of failure zones under slope surface in different stress ratio. When the stope is opened in higher horizontal stress condition, the differential stresses acting to rock mass are larger than that of lower stress ratio as shown in Fig. **8**. One of the reason is the cause of stress flow which passes through around the excavation. As the stress ratio becomes higher, the trend of gravitational field stress goes perpendicular to the induced tangential stress, therefore it can be expected the rock mass around the excavation might be more disturbed. This condition is proved in Fig. **9** which show the model with higher horizontal stress ratio meet more severe condition with shear and tensile failure than the one with higher vertical stress ratio.

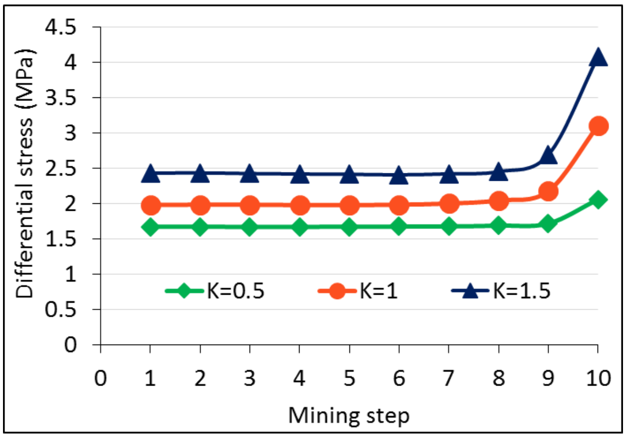


Fig. 8. Differential stresses measured in various stress ratio.

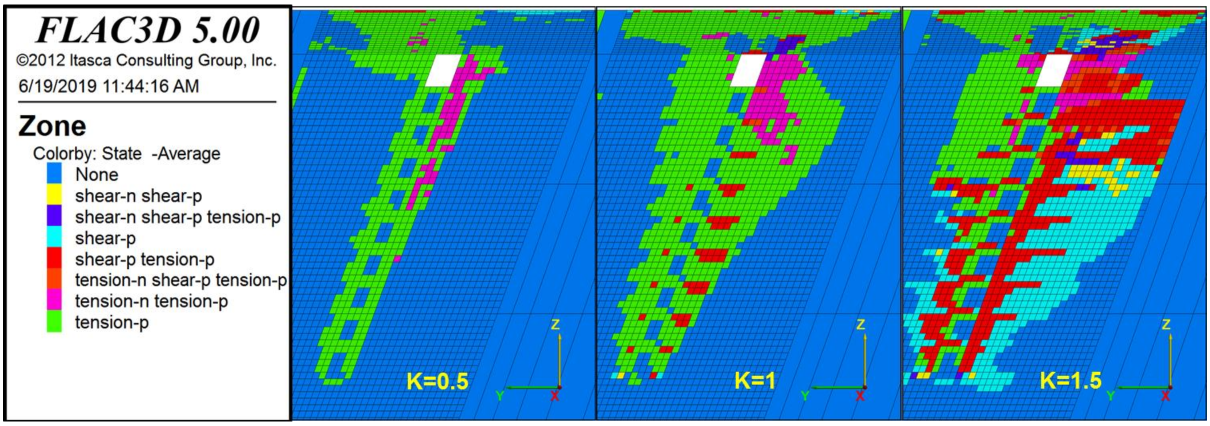


Fig. 9. Failure zones occurred in different stress condition.

## 4. Conclusion

Mining activities under slope topography may affect more on the variation of stress and failure zones than other places of rock mass due to the risks of the sloping condition. From the investigation of rock mass condition near the slope surface, the results indicate that the rock mass strength is gradually decreased heading to the slope surface. When the mining sequence is advancing under the slope surface, the occurrence of failure zones is more propagated to the excavation near the slope surface. On the contrary, the mining activities far from the slope are likely affected by its own induced stress, therefore the failure zone only occur around the stope mining without propagating to the surrounding rock mass. Form the simulation with different rock mass properties, the results show that the potential of stope failure might be experienced more in lower GSI than that of higher GSI. Both tensile and shear failure occur more severe as the geological condition become worse. Therefore, mining in poor ground should be paid more attention to avoid stress-induced rock mass failure. In addition, from the simulation with different stress ratio, it can be expected the rock mass around the excavation might be more disturbed by induced differential stresses and the possibility of failure zones might be large in higher stress ratio. Therefore, more supporting capacity is needed to stabilize the stope mining in the near-ground part in higher stress ratio condition.

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