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Evaluation on the instabilities of stope mining influenced by the risks of slope surface and previous mined-out activities

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Abstract. Open stope mining is the most common mining method adopted in underground metal mines in Myanmar. However, the assessments on the stability of stope still remain quite limited for this method in underground mining. Even though mining objective is to recover ore as much as possible from the vein, safety of workers and machinery in the advancing stopes must be ensured. The main reasons for the occurrence of underground mine's instabilities come from the stress redistribution in the surrounding previous mined-out activities, the existence of discontinuities and void space, and the influence of on-going mining activities, etc. In addition to these problems, if the underground mining is located near the slope surface, the influence of slope surface should be taken into account to that mining activities. Therefore, considering the importance of rock stability in open stope, the investigations on the stability of advancing stope surrounding the previous mined-out behave together with the influence of slope surface are conducted at Modi Taung gold mine, one of the largest underground gold mines in Myanmar. In this research, the investigations on the stability of open stope are conducted with the variation of differential stress subjected to the rock mass at the planned-mining zones and displacement of stope's surface in each stope mining activities. From the preliminary outcome of this research, the results show that the rock mass near the slope surface can be more subjected by differential stress than inside of the rock mass. Moreover, the results highlight that the potential buckling failures from hanging wall and foot wall are more severe than the roof fall from the stope's roof in this mine site. All of these investigations are conducted by means of 3D finite difference software using FLAC^{3D}.

Keywords: Instability, Previous mined-out, Slope surface, Stope mining

1 Introduction

Myanmar has more than 300 prospected gold deposits across the country as shown in figure 1 [1]. Gold deposits are classified as either primary or alluvial types and the mining method used in these gold deposits are both surface and underground.

Previously, most of the underground mines across the country are operating at the easily assessable shallow regions. However, in recent years, underground mining activities are going to move into deeper places to fulfill the mineral supply. As the depth of mines increase, the occurrence of higher induced stress is becoming a more common phenomenon causing some problems for instability and safety of mines. The stability of underground mines may be influenced by many factors such as the quality of rock, the existence of discontinuities and void space, in-situ stress conditions, the influence of previous mined-out and on-going mining activities, and mining depth, etc. In addition to these factors, if the underground mining is located near the slope surface, the influence of slope surface should be taken into account to that mining activities. Therefore, considering the importance of rock stability in underground mines, the investigations on the stability of advancing stope surrounding the previous mined-out behave together with the influence of slope surface are conducted at Modi Taung gold mine, one of the largest underground gold mines in Myanmar.

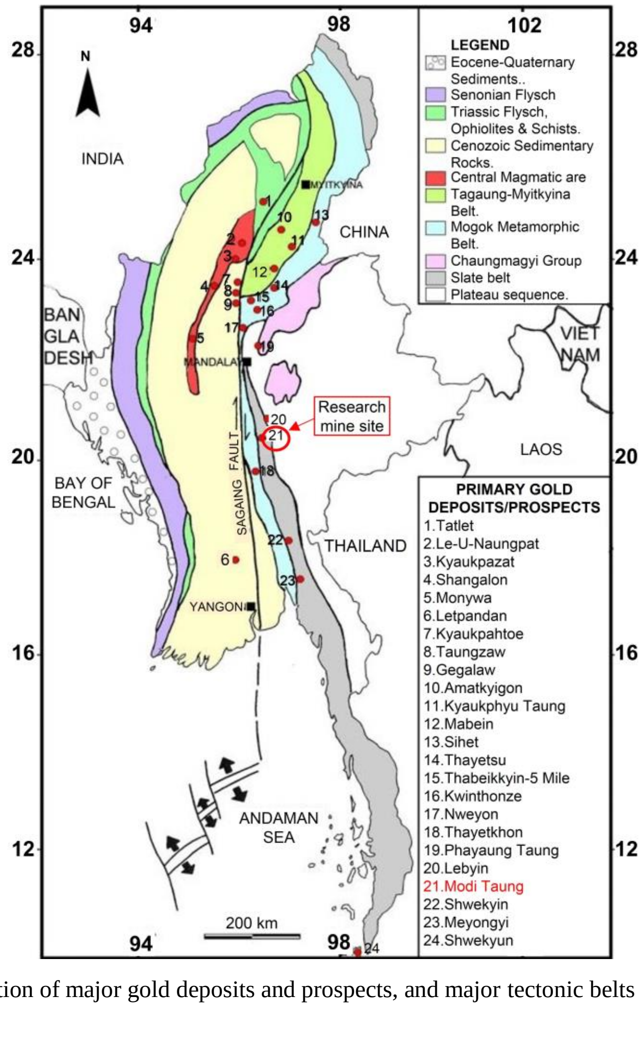

Fig. 1. Location of major gold deposits and prospects, and major tectonic belts in Myanmar

2 Brief lithology and mine plan at Modi Taung gold mine

Veins at Modi Taung gold mine are hosted by four main lithologies such as mudstone, sandstone-siltstone, limey sandstone or limestone, and igneous intrusions. Host rocks in Shwesin vein are predominantly mudstone but sandstone occupies short segments an all levels, and veins tend to occur along the inclined interface between sandstone and mudstone [2].

The accessible shallow area has been already mined out at Shwesin vein system of Modi Taung gold mine, hence, the deposits are left in deeper regions. Therefore, the mining plans continue to deeper levels which are separated into 6 blocks, namely from block 1 to block 6. The overall mine plan is illustrated in Figure 2 and overhand cut and fill method is adopted to extract the minerals at Shwesin vein. The waste rocks from excavation are only used to both fill the stope and provide permanent wall support for the lower mine out cavity. Vein dipping at Shwesin vein are up to 80 degrees and vein thickness varies with elevation ranging from 40 cm to 140 cm [3]. In this research, the mining activities are conducted at Block 3 which is separated with zone 1, 2 and 3, and this block is surrounded by the previous mined-out activities together with the influence of slope surface as shown in figure 3. Therefore, the mining activities in this block might be affected by the redistributed and accumulated stresses from the previous mined-out activities. This accumulation of stress in the rock mass may lead to destructive stress that can cause the instability of on-going stope mining in Block 3. Furthermore, the mining plan at Block 3 is located near the slope surface, accordingly, the effect of slope surface also might be influenced to the mining activities. Even though the most serious part of rock strength is appeared at the edge of the slope, the instability of the rock mass is gradually propagated into the rock mass from the slope surface as shown in figure 4.

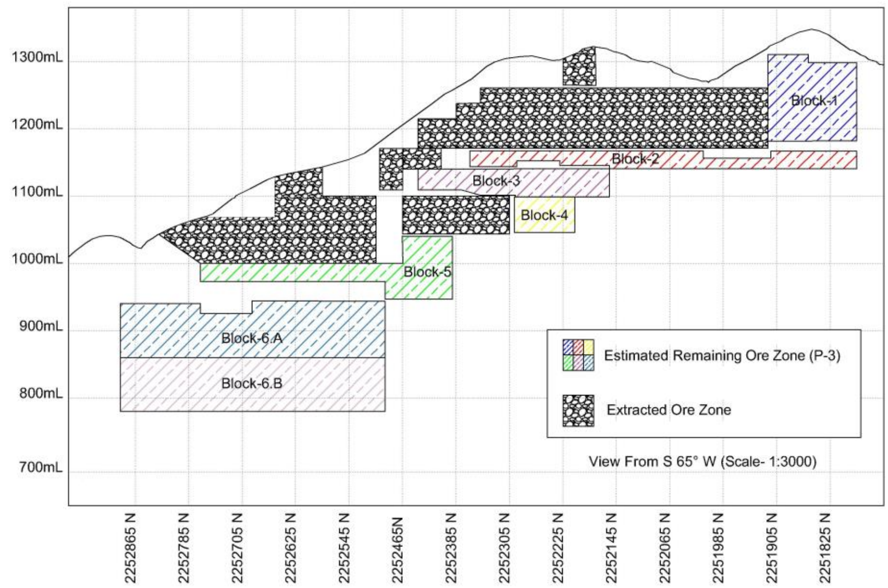

Fig. 2. Simplified mine plan at Shwesin vein (source: NPGPGL).

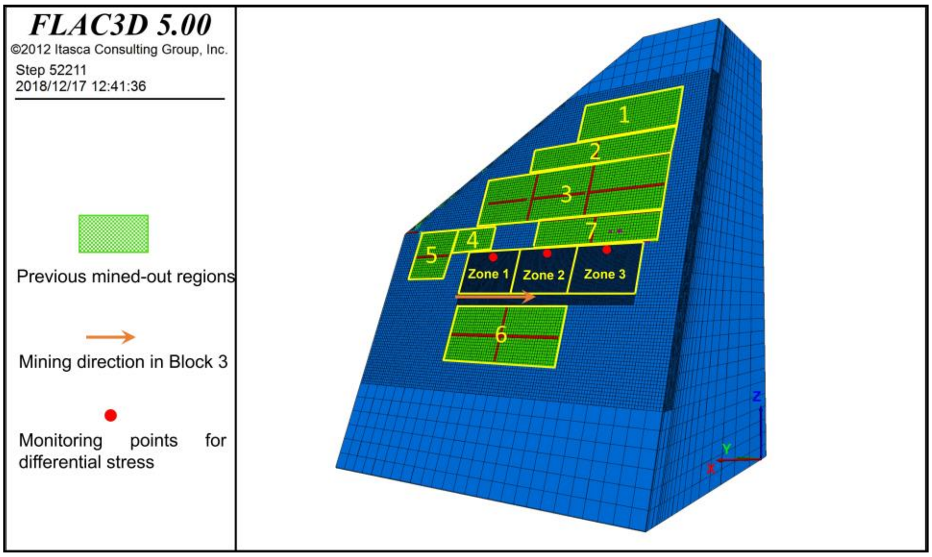

Fig. 3. Mining condition surrounded by previous mined-out and slope surface in Block 3

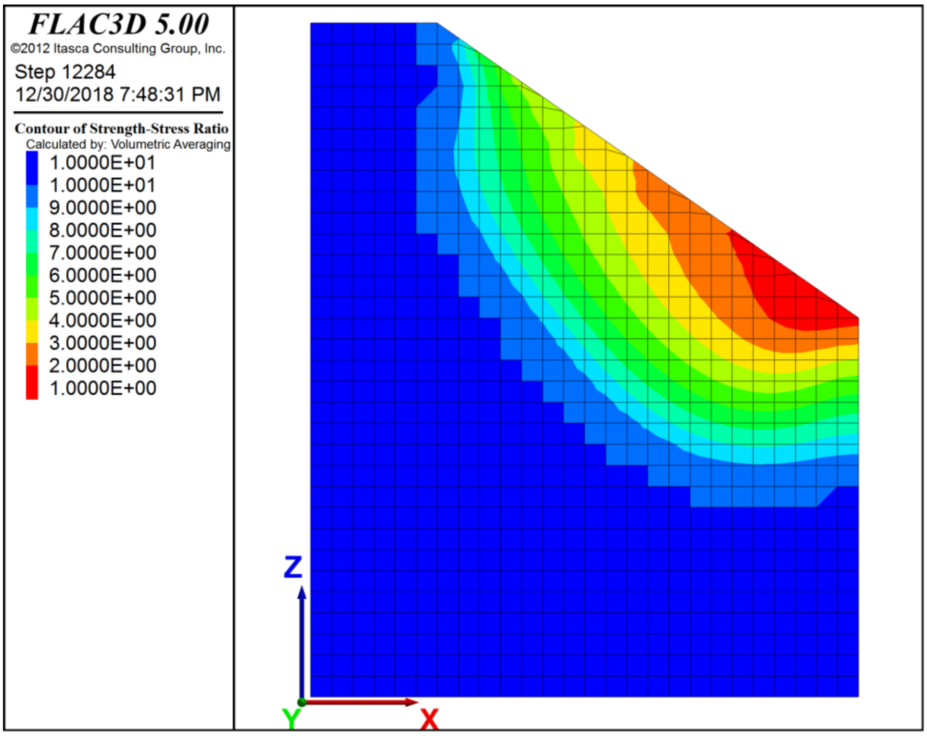

Fig. 4. The condition of rock mass strength near slope surface

3 Numerical model

Numerical modelling was carried out with FLAC^{3D} software which is used for stress and deformation around surface and underground structure opened in both soil and rock [4]. In this study, the size of basic numerical model is 260 m × 260 m × 320 m with 70 degree in vein dip as shown in Figure 5. As the slaty mudstone is a dominant rock type in Modi Taung gold mine, and therefore, the hanging wall and footwall are assigned as homogenous model for simplification. All mechanical properties of rock used in this study are shown in table 1. The stoping sequence in Block 3 takes place from the lower slice to upwards direction as shown in Figure 6 and the dimension of stope is 2.5 m in height and 2 m in width.

In order to know the stability of stope, a failure criterion must be selected. A factor of safety of 1.3 would generally be considered as a stability standard for a temporary mine opening while a value of 1.5 to 2.0 may be required for a permanent excavation [5]. In this research, the Mohr-Coulomb failure criterion is adopted and the stope was considered in a stable condition when Mohr-Coulomb safety factor is greater than 1.3 and unstable condition will meet when safety factor is less than 1.3.

Moreover, in order to understand the potential instability of the rock mass at Block 3, the monitoring points near the top of each mining zone are placed to measure the changing of differential stress. Furthermore, during mining sequence in Block 3, the monitoring data are collected at hanging wall, foot wall and roof of each stope in order to know the displacement of stope's ribs and roof.

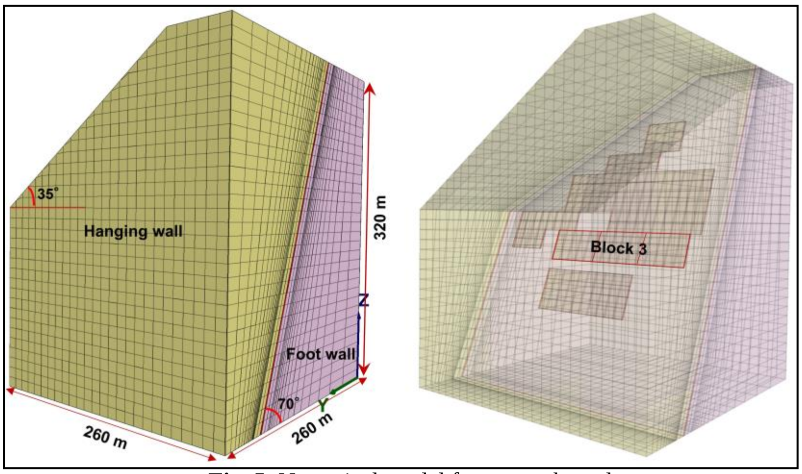

Fig. 5. Numerical model for research study

Table 1. Rock mass properties used in analyses.

	E [MPa]	v [-]	σ_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

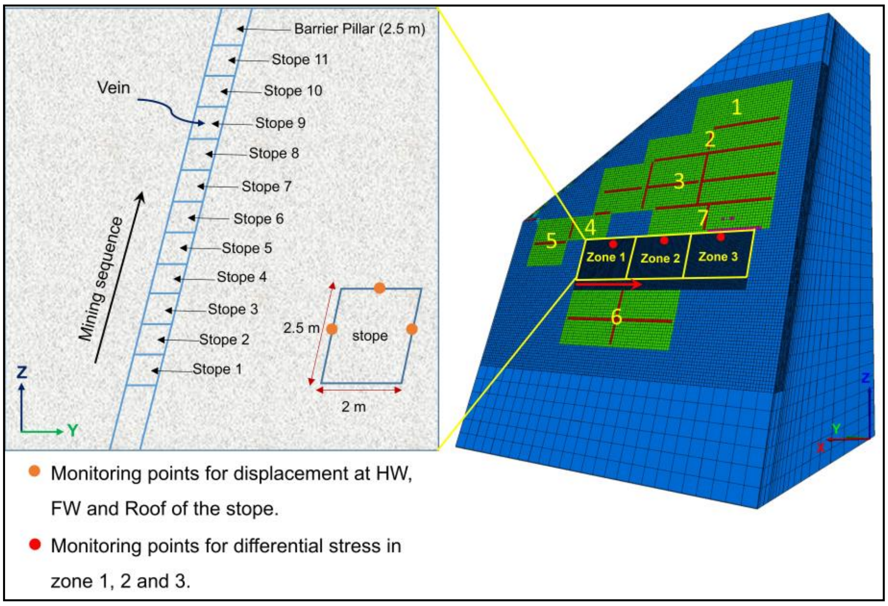

Fig. 6. Mining sequence in zone 1, 2 and 3 at Block 3.

4 Results and discussions

In this study, the strength of rock mass near the slope surface is analyzed by the variation of differential stress during the previous mined-out activities. As well known, differential stress is the difference between the major and minor principal stresses and rock mass can deform (break/flow) due to differential stress. Moreover, in order to understand the stability of stope in planned-mining zone 1, 2 and 3, the differential stress from barrier pillar and the displacement from stope's ribs and roof are recorded during the mining progress in zone 1, 2 and 3 as shown in figure 6. During the simulations, the strength of rock mass and the stability of stope are monitored with two stages.

4.1 Strength of rock mass and stability of stope mining

4.1.1 Strength of rock mass affected by slope surface

At first, the strength of rock mass is investigated in zone 1, 2 and 3 by monitoring with differential stress during the previous mined-out activities together with the influence of slope surface as shown in figure 3. In this stage, the mining activities are done only in previous mined-out regions through 1 to 7 and not operating in zone 1, 2 and 3. Figure 7 presents the distribution of differential stress at various previous mined-out regions and figure 4 shows contour of strength to stress ratio near the slope surface. Even though the most serious part is the base of the slope surface as shown in figure 4, the instabilities of rock mass were gradually propagated into the rock mass.

As can be seen in figure 7, the result show that the amount of differential stress in zone 1 is higher than that of zone 2 and 3 except the data from the previous mined-out region 7. As the monitoring point is closed to the mined-out region 7, the differential stress collected at that area is immediately increased. Logically, the stresses subjected to the rock mass in zone 3 will be maintained more equilibrium than that of zone 1 and 2. However, as the monitoring point move to the rock mass nearer to the slope surface (i.e., from zone 3 to zone 1), perhaps the difference between the principal stresses are gradually increased because the overburden from the monitoring point is progressively decreased due to the slope surface. Therefore, according to this result, it can be said that the rock mass near the slope surface can be more affected by differential stress than that of inner part, and this result highlights the importance of rock stability when the underground mining activities operate near the slope surface.

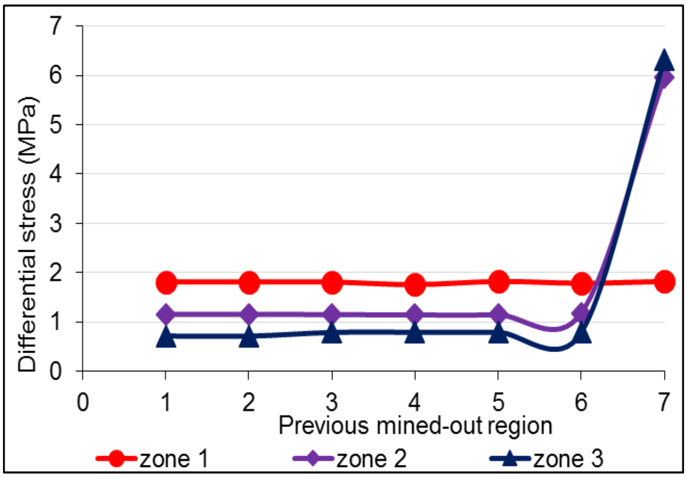

Fig. 7. Differential stress indicators during the previous mined-out activities together with the influence of slope surface

4.1.2 Instability of stope during planned-mining zones 1, 2 and 3

Figure 8 shows the condition of differential stresses during the stope mining in planned-mining zones 1, 2 and 3. In this result, it can be seen that the differential stresses in zone 2 and 3 are higher than zone 1. This trends indicates the potential instability of rock mass in zone 2 and 3 reaches more serious condition than that of zone 1. One of the reason for this condition is the effect of mining activities repeatedly from zone 1 to 3. When the mining activities operate in zone 2 and 3, the influence of induced stresses from previous mined-out activities behave together with the effect of slope surface already affect to the mining zone 1. Afterwards, on-going mining activities are being carried out upwards repeatedly in the bound of the ore body in zone 2 and 3, therefore the surrounding rock masses are continuously disturbed and the intense redistributed stresses are affected to the rock masses in later mining zones. The development of instabilities increasing around the stope can be clearly observed in figure 9 and 10 that describe the occurrence of failure zones and contour of safety factor in zone 1, 2 and 3.

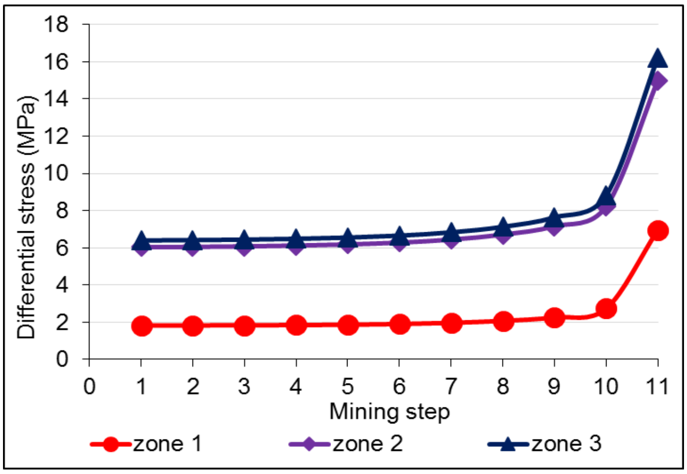

Fig. 8. Differential stress indicators during planned-mining zone 1, 2 and 3.

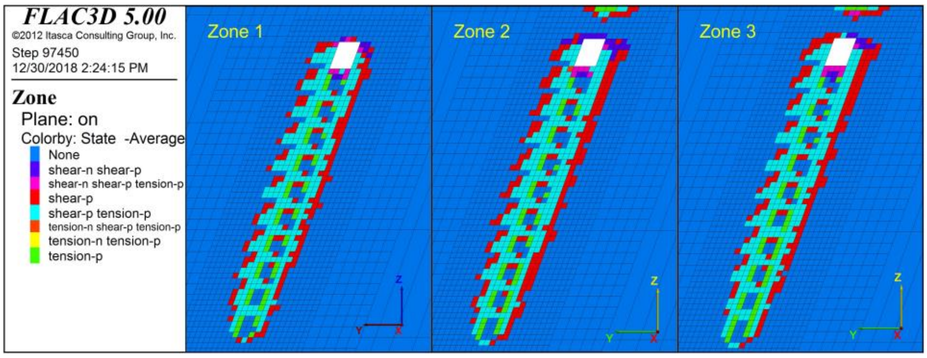

Fig. 9. Failure zones in mining zone 1, 2 and 3

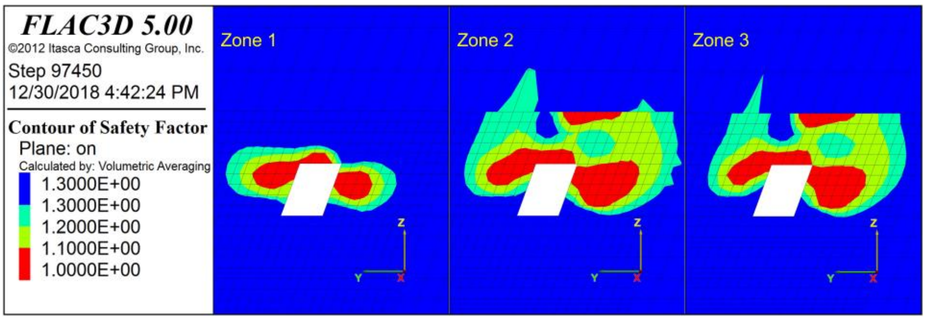

Fig. 10. Contour of safety factor in mining zone 1, 2 and 3

4.2 Displacement of ribs and roof of stope

Common mining instabilities in underground cut and fill stoping include roof falls and rib falls of the stope. To obtain a comprehensive understanding of the deformation from the roof and ribs of the stope, the monitoring data from the surface of roof and ribs of the stope is collected during the stope mining in planned-mining zones 1, 2 and 3 as shown in figure 6. All the results collected from hanging wall, footwall and roof of the stope are shown in figure 11, 12 and 13.

From the results of figure 11, it can be seen that the displacement from hanging wall of each stope is steadily decreased and it reached at the maximum with 20.6 mm in zone 3, 19 mm in zone 2, 12.3 mm in zone 1 and 10.9 mm in zone 3 without the effects of previous mined-out. Meanwhile, according to figure 12, the displacement from foot wall of each stoping is reached at the maximum with 18.7 mm in zone 3, 17.3 mm in zone 2, 9.9 mm in zone 1 and 10.9 mm in zone 3 without the effects of previous mined-out. Furthermore, according to figure 13, the displacement from roof of each stope is reached at the maximum with 13.2 mm in zone 3, 10.2 mm in zone 2, 4 mm in zone 1 and 2 mm in zone 3 without the effects of previous mined-out. By seeing all of these graphs, the displacement of rock mass from hanging wall and foot wall are higher than stope's roof. This results indicate that the potential buckling failures from hanging wall and foot wall are more severe than the roof fall from the stope's roof in this mine site.

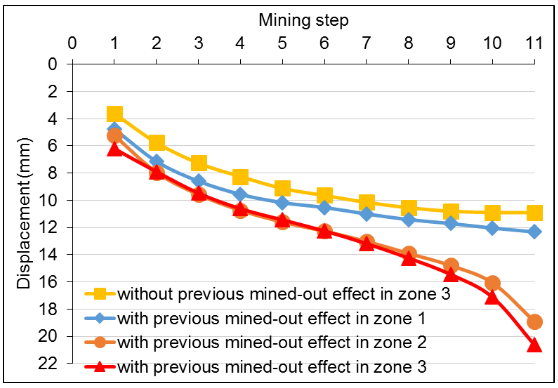

Fig. 11. Displacement from hanging wall of stope at various mining step

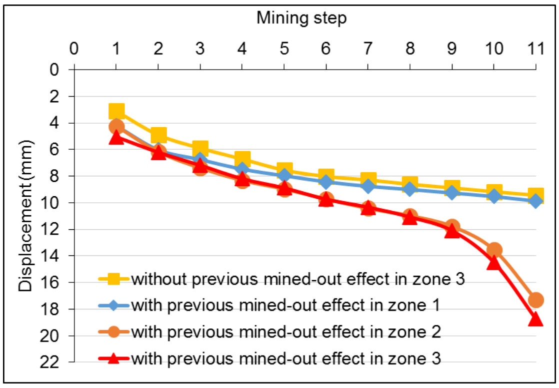

Fig. 12. Displacement from footwall of stope at various mining step

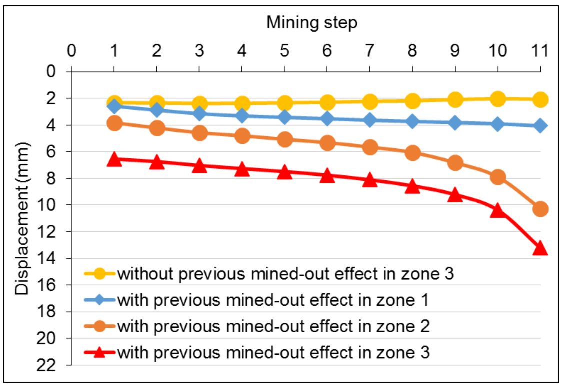

Fig. 13. Displacement from the roof of stope at various mining step

3 Conclusion

This paper presents the FLAC^{3D} simulations to investigate the stability of planned-mining zones with the influence of induced stresses from the previous mined-out activities behave together with the effect of slope surface. The analysis results show that the rock mass near the slope surface can be more affected by differential stress than that of inner part, and this result highlights the importance of rock stability whenever the underground mining activities operate near the slope surface. Moreover, if the rock masses are steadily disturbed by the induced stresses from previous mined-out activities, the intense redistributed stresses can be affected to the stability of rock masses in later mining zones. Thus, the potential instabilities will be more developed to later mining zones. Furthermore, from the analysis on the displacement of stope, the results highlight that the potential buckling failures from hanging wall and foot wall are more severe than the roof fall from the stope's roof in this mine site.

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