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CONTENTS

STRESS DISTRIBUTION AND DISPLACEMENT ANALYSIS IN A STOPE IN PONGKOR UNDERGROUND GOLD MINE

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ABSTRACT

Pongkor is one of the underground gold mines in Indonesia which applies the cut-and-fill mining method. During the mining, the stability of mine opening is one of the factors deciding the continuity of underground mining process. Due to the mining activity, stresses around the mining area will be redistributed, and in some condition they may lead to a failure on the stope. To avoid such failure, it is important to monitor the deformation and understand the stress redistribution effects on surrounding rock mass as the mining activity proceeded. A borehole extensometer was installed in the ore body to monitor the rock mass displacement, and a 3D model of the mining sequence was made to understand the stress redistribution in the surrounding rock mass.

INTRODUCTION

Pongkor underground gold mine carries out a cut–and-fill mining method to excavate the vein ore body. The stope mining activity is carried out in slice which is 100m in length, 3m in height and the width follows the potential ore body. In some occasion, failures happen around the stope opening, mostly in the stope roof, which may affect the mining activity. To avoid such condition, analysis is carried out to understand the influence stress distribution due to stope mining activity of the surrounding rock mass through a monitoring station located above the stope.

The aim of this study is to analyze the stress redistribution and rock deformation in the roof due to stoping activity. Deformation analysis was carried out by drilling a set of borehole in a crosscut located above the stope and the stress redistribution in surrounding rock mass is analyzed by using a 3D model regarding the mining location and mining sequence. This research is a continuation of the previous study carried out by Dwinagara, et.al., 2006.

NUMERICAL MODELLING

Numerical modeling was carried out to understand the stress redistribution due to mining activities located below the monitoring station. The model was also used to verify the direct measurement (horizontal extensometer). FLAC3D program was used to analyze the stress redistribution by assuming the rock mass as continuous material. The model represented the location of monitoring station in crosscut 6A in Level 500 of Block II Central Ciurug, at an elevation of 568 m, around 300 m from the surface (Dwinagara, et.al., 2006). The stope was located below monitoring station, and the vertical distance between the floor of crosscut 6A and the stope roof was about 3 m. As can be seen in Figure 1, the stoping was started from the stope 1 (located at bottom part) and move upward to higher stope number (stope 10). The length of each stope excavation was about to 10m. Due to the stope mining process, stresses in rock mass around the monitoring station were affected.

The inputs for the numerical model were stope geometry, mining sequences, rock mass properties, and in situ stresses at the location. The stope was approximately 5 m wide and the thickness of mining slice was 3 m. Rock mass properties were taken from the laboratory test (See Table 1). The in situ stresses used as the input in this model were obtained from previous research located near to this location (Sulistanto, et.al., 2003) (See Table 2).

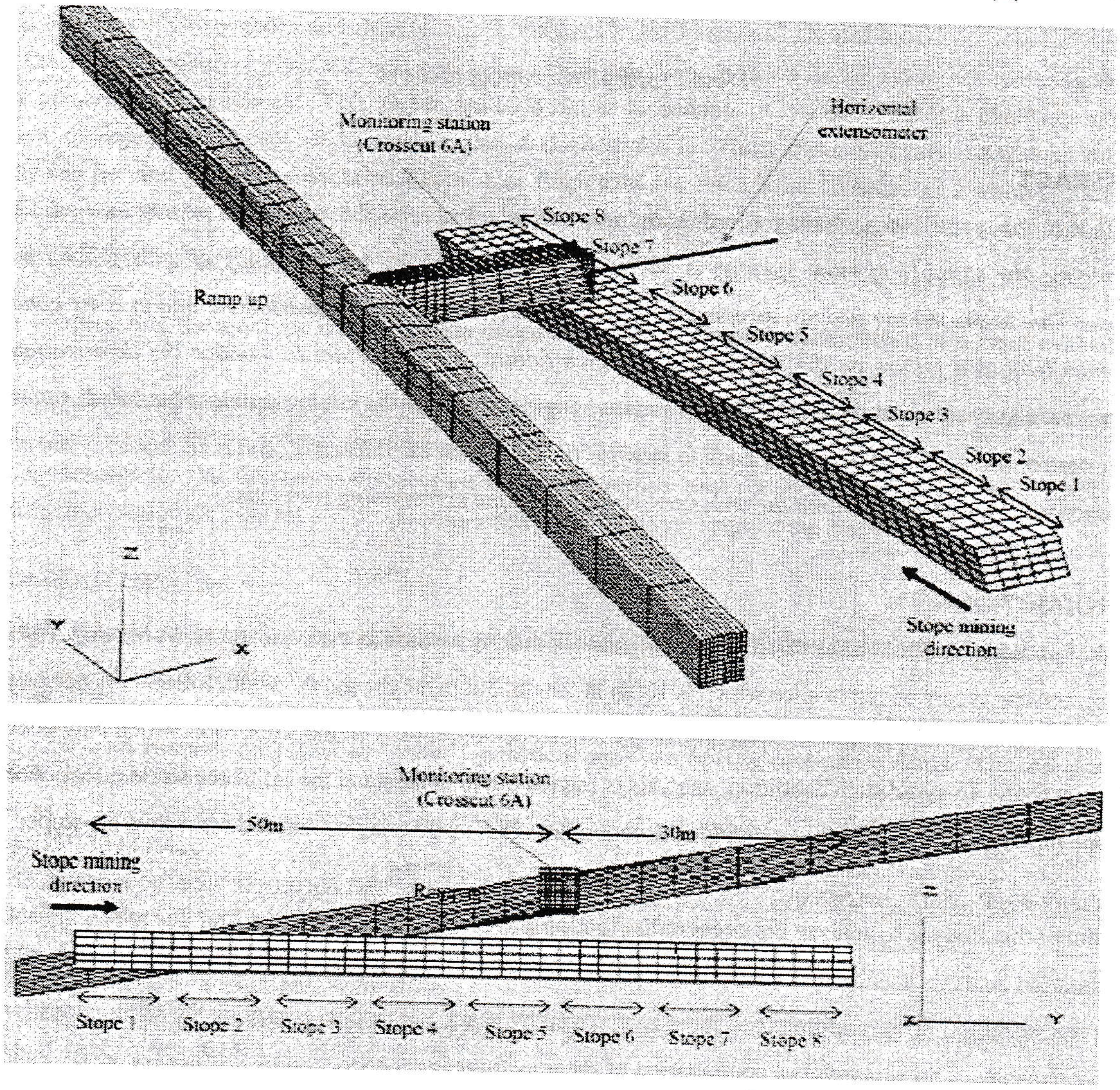


Figure 1. Numerical Model of the Location and Stope Mining Direction

Table 1. Rock Properties

Rock Type	γ (kN/m^3)	E (GPa)	ν
Andesitic Breccia (FW & HW)	27.3	12.35	0.26
Vein	26.9	5.25	0.26

Table 2. Insitu Stresses

Stress	Magnitude	
σ_x	0.61	MPa
σ_y	3.62	MPa
σ_z	3.88	MPa
σ_{xy}	0.73	MPa
σ_{yz}	0.79	MPa
σ_{xz}	-0.83	MPa

DISPLACEMENT MEASUREMENT

The displacement measurement was carried out from the monitoring station at crosscut 6A, by using *Intrinsically Safe Magnesonic Probe Extensometer* of Type 1062. Two boreholes which oriented horizontally and vertically were drilled into the vein to install the extensometer magnetic anchors ($T_0 - T_4$), as illustrated in Figure 2. Since this analysis was focused on the stability of the stope's roof, only the horizontal extensometer displacements were taken into account.

The displacement calculation was based on the change of distance between the two magnetic anchors as follows:

$$\Delta L = L_t - L_0 \tag{1}$$

Where: ΔL = distance change (displacement), mm

L_t = final distance at time t, mm

L_0 = initial distance, mm

The initial positions of the horizontal magnetic anchors are listed in Table 3. At the beginning of the measurement, the stope was approximately 45 m (horizontal) from the station. The mining then moved towards the station (distance of 0 m) and then passed the station.

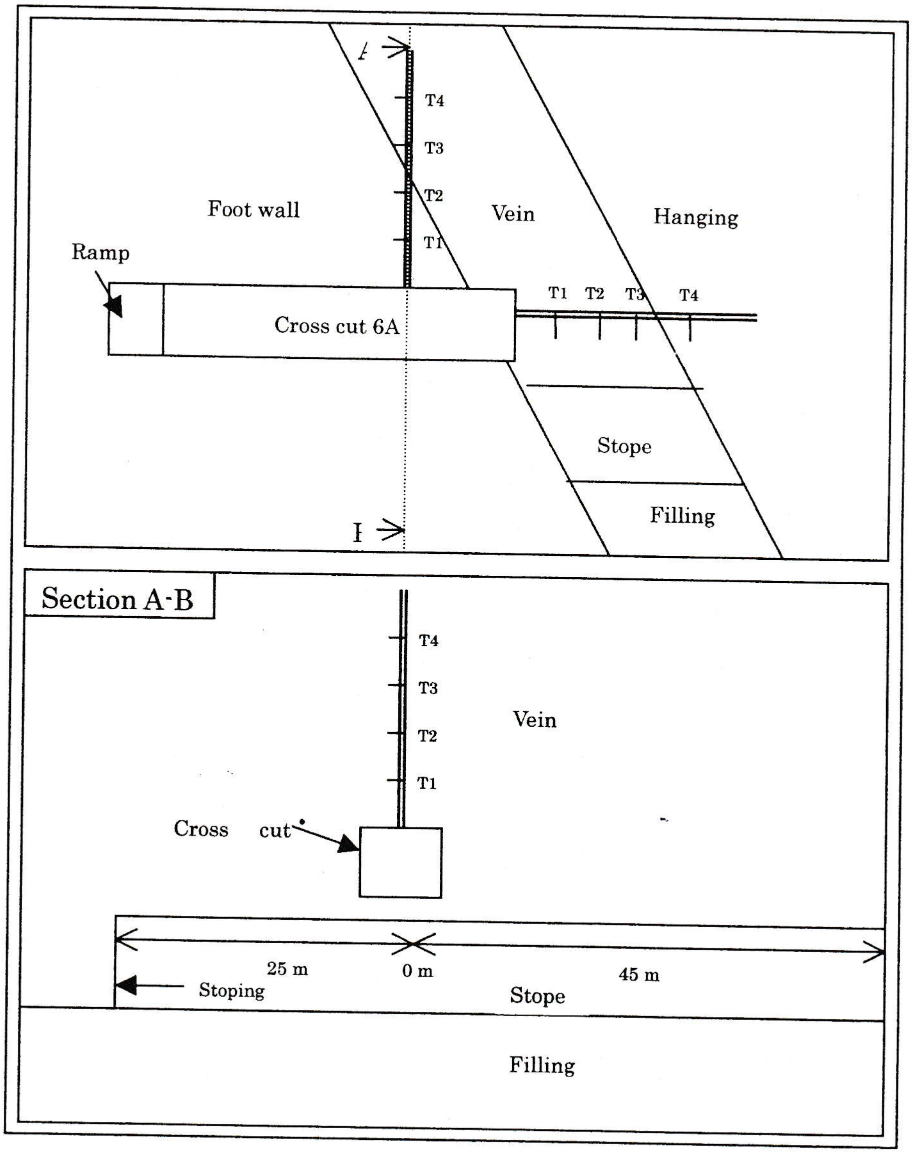


Figure 2. Magnetic Anchors Placement in Borehole (Dwinagara, et.al., 2006)

Table 3. Initial Positions of Horizontal Magnetic Anchors from Collars

Anchor	*Front Borehole*	
	Position	*Rock*
T_1	1146 mm	Vein
T_2	2365 mm	Vein
T_3	3867 mm	Vein
T_4	5887 mm	Hanging wall

Graphs depicting the accumulative displacements of front borehole as the stoping move forward to the station and passed the station are given in Figure 3.

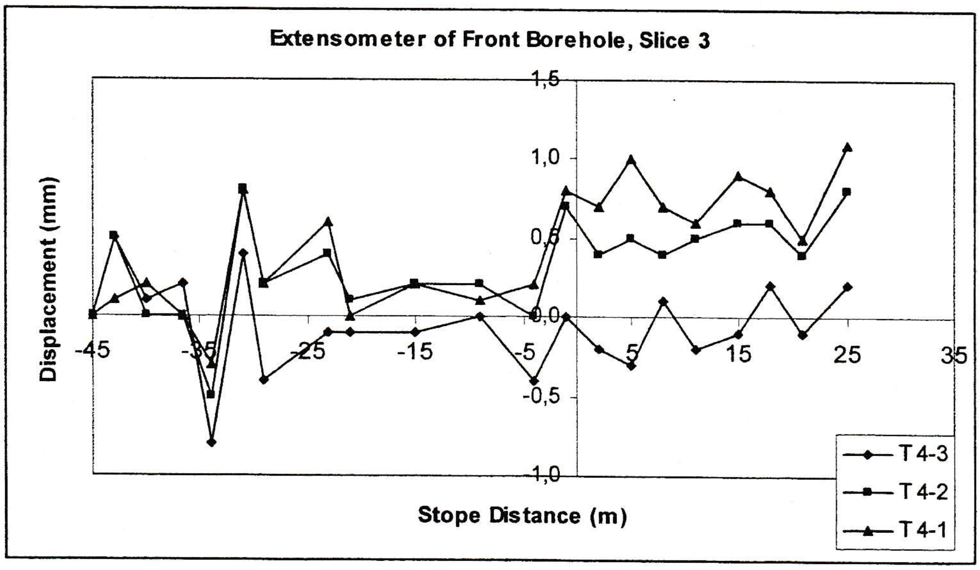
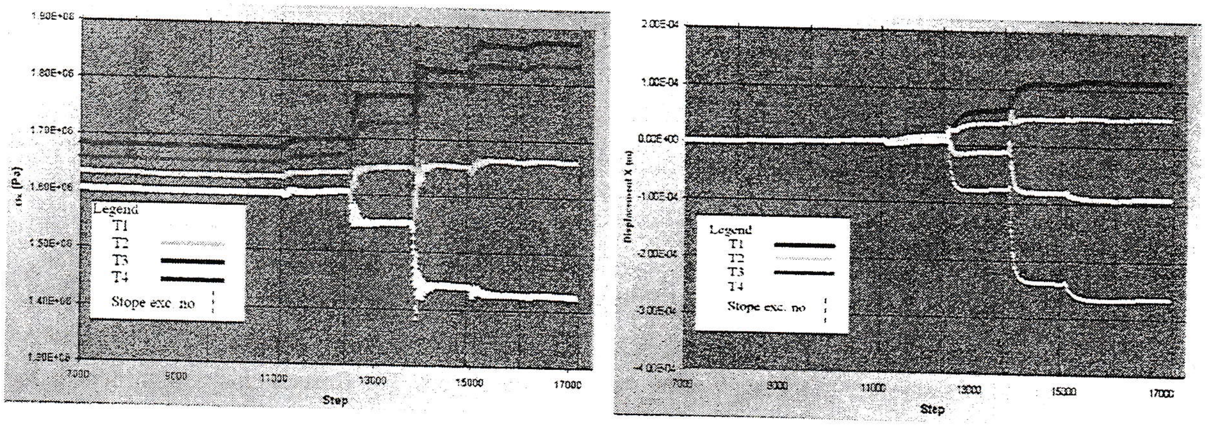


Figure 3. Accumulative Displacement along Horizontal Borehole Extensometer (Dwinagara, et.al., 2006)

STRESS AND DEFORMATION RESULT FROM NUMERICAL MODELING

Stress distribution change was monitored in some points. The location points which were analyzed in the numerical model were the same as the horizontal extensometer monitoring points. As the horizontal points were located in the both edges and in the middle of the ore body, they may be considered representing the behaviour of the ore body in the horizontal direction.

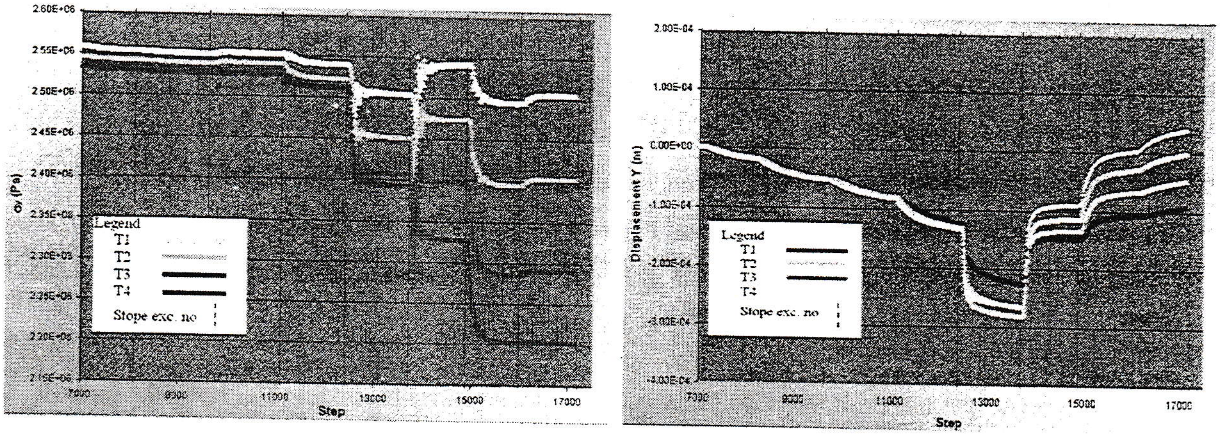
Due to stope mining activities located beneath the monitoring station, the monitoring points located in the ore body would suffer stress redistribution. The analysis was also conducted on the rock mass deformation in the same points. The result of the stress change and deformation from numerical model are shown in Figure 4 to Figure 6.



(a) Stress change

(b) Deformation change

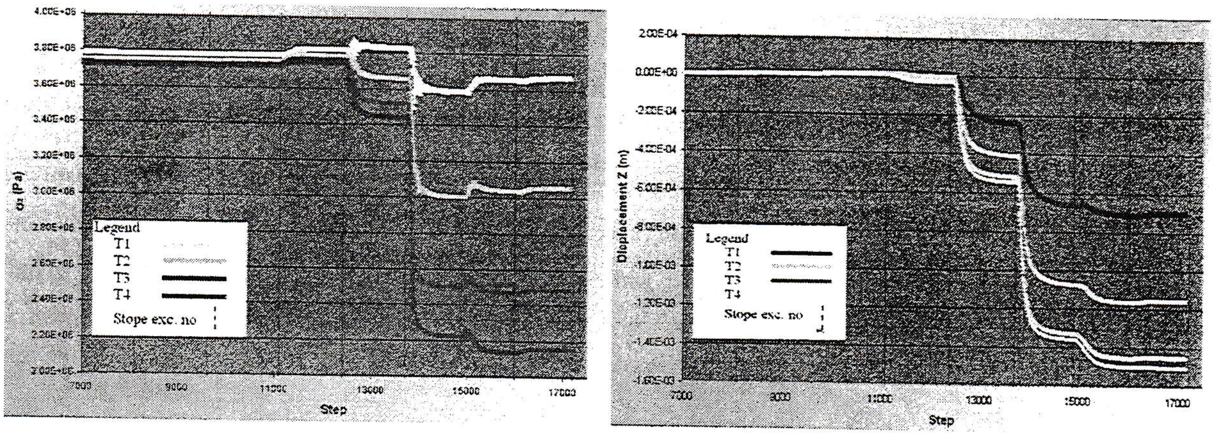
Figure 4. Stress and Deformation Change in X Axis Direction



(a) Stress change

(b) Deformation change

Figure 5. Stress and Deformation Change in Y Axis Direction



(a) Stress change

(b) Deformation change

Figure 6. Stress and Deformation Change in Z Axis Direction

DISCUSSION

Stoping induced stress

The stoping which is moving forward to the monitoring station and located beneath will affect the stress distribution around this location. The data obtained from numerical model shows that the points which were monitored also suffer stress redistribution.

Figures 4 to 6 show that the effect of stoping to stress redistribution started when the stope 4 was excavated. The horizontal distance of stope face to the monitoring station is about 20m. The stresses change significantly when stopes 5 and 6 were excavated. The location of those stopes which are on the lower right from the monitoring station, was the cause of the significant stress change. When the stopes were excavated an opening was formed right below the monitoring station causing major stress redistribution around the location. The stresses tended to be relatively constant after the excavation of stope 7 which horizontal distance of stope mining was about 20m.

Displacement Comparison between Extensometer Measurement and Numerical Modelling

By using the deformation data obtained from the numerical modelling (Figure 4-6), the movement of the monitoring points could be well understood. From those figures, it can be found that the stope started to influence the monitoring point after stope 4 was excavated. Figure 4 shows that the deformations in the x-direction show a tendency that the points became closer to each other. T1 and T2 moved forward (positive x-direction) while and T3 and T4 moves backward (negative x-direction). The deformation ranged from 0.1m to 0.25mm.

Figure 5 shows that the y-direction deformation of the rock mass had a tendency to move toward to location where mine opening exists. As can be seen that before the excavating of stope 5, the points moved to the right (negative y-direction) and after passing stope 5, the points moved to left (positive y direction). The displacement ranged from -0.28mm to 0.14mm. The z-direction displacement show that all points moved downward. As the point located farther from footwall, the displacement value will be higher. The z deformation value ranges from 0.7mm to 1.5mm.

Since the data obtained from borehole extensometer measurement is only in x-axis, the best way to compare to the numerical data was do the analysis in 2 dimension (x axis and z axis). The coordinate of monitoring points before and after stope excavation are given in Table 4, while the distances between monitoring anchors are given in Table 5.

Table 4. Monitoring Points Coordinate in Numerical Model

Points	*Before stope excavation*		*After stope excavation*	
	X	*Z*	*ΔX*	*ΔZ*
T1	30.147	22	$4.3E^{-04}$	$-2.3E^{-03}$
T2	31.365	22	$2.1E^{-04}$	$-3.8E^{-03}$
T3	32.867	22	$-2.5E^{-04}$	$-4.8E^{-03}$
T4	32.887	22	$-8.3E^{-04}$	$-4.9E^{-03}$

Table 5. Distance Change of Monitoring Points from Numerical Model

Points	Distance (m)		
	Before stope excavation	After stope excavation	Delta
T4-3	2.02	2.019421499	$-1.26E^{-03}$
T4-2	3.522	3.520954588	$-1.05E^{-03}$
T4-1	4.74	4.738742431	$-5.79E^{-04}$

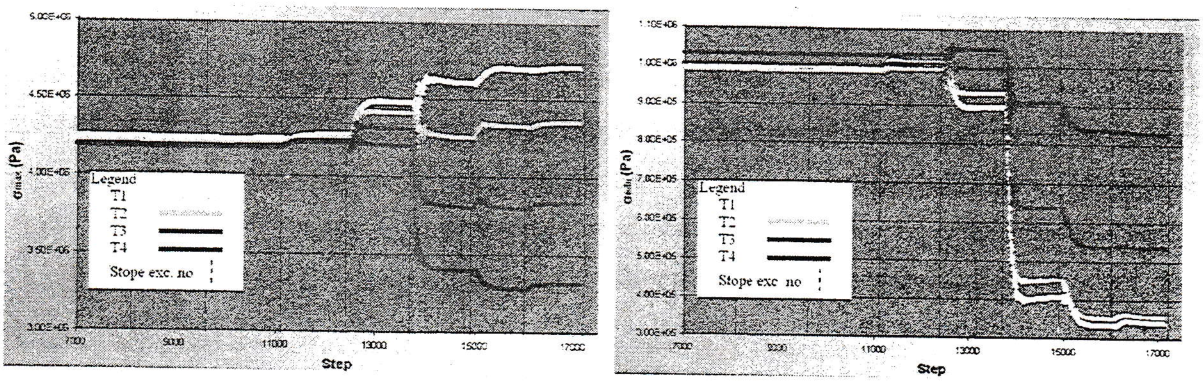
The distance change of monitoring points from numerical model revealed that there was a shortening along horizontal borehole extensometer and different from direct measurement result (Figure 3) which showed an extension. It may happen due to the existence of geological structures which developed around the location and which was not included in the numerical model.

STABILITY OF STOPE'S ROOF DUE TO MINING ACTIVITY

One of the factors which may lead to underground instability is the induced stress around the opening. The mining activity it self can change the condition of insitu stress. During the stope mining activity, the maximum stress (σ_1) and minimum stress (σ_3) in the monitoring points suffer changes. In this work, the monitoring points were located in the rock mass which acts as stope's roof. As can be seen in Figure 7, the maximum stress started to increase when stope 5 was excavated due to stress redistribution. Since there was an opening near the monitoring station, the stress was transferred to neighbouring rock mass, which one of monitoring stations (horizontal extensometer) was located.

The maximum stress in T1 increased while stresses in other points relatively decreased. This condition was due to the geometry of the opening which may cause the stress to concentrate at some of the edges of the opening, while in other edges the stress was redistributed.

Figure 7 also shows that the minimum stress in all monitoring points decrease. At the edge of the opening which is represented by T1, the combination of increasing maximum stress and decreasing minimum stress means that the loading condition is increasing. As the loading condition increases and the rock mass strength is constant the safety factor value for the underground opening will be decrease.



(a) Maximum stress (σ_1) change (b) Minimum stress (σ_3) change

Figure 7. Maximum and Minimum Stress changes

CONCLUSION

From the analysis above, it can be seen that the stress started to affect the monitoring points and leave the steady condition when the horizontal distance from the stope face was approximately 20m. The extension of horizontal borehole extensometer from direct measurement was caused by the existence of geological structure rather than the stress redistribution, as the continuous numerical model shows the opposite result.

The stress redistribution in the stope roof caused by stoping activity with its specific opening geometry, caused a stress concentration the edge of the opening. The stress redistribution may cause the increasing of rock mass loading condition and decrease the safety factor of the opening.

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