Stability analysis of pastefill used for backfill material at Kencana Underground Gold Mine, North Halmahera, Indonesia

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ABSTRACT

PT Nusa Halmahera Minerals (NHM) is a gold mining company which located in North Halmahera, North Maluku Province, Indonesia. One of NHM mine site is Kencana Underground Gold Mine which applying Underhand Cut and Fill (UCF) mining method. Backfill material used in this side is pastefill type. Stability analysis of pastefill block needs to be carried out due to the reason that it will act as back (roof) when underneath stope is opened. This research is carried out in Kencana 2 Sub 12 C undercut 3 Ore Drive (OD) 1 North. The stability of pastefill block is analyzed by applying numerical analysis using 3DEC software Ver. 2 from ITASCA and analytical analysis using limit equilibrium method. Mechanical and physical characteristics of rock is obtained from NHM while the one of pastefill is obtained from laboratory testing. From the result of numerical analysis, pastefill with 14% cement content and 7 or 28 days curing time will collapse through caving failure mechanism on 6 m span. This result is in a good agreement with limit equilibrium analysis where caving failure mechanism will occur at 6 m span. To overcome this instability, reinforcement materials consist of chain link mesh and stand up bolt are installed at the floor of mined out stope before pastefill placing is conducted. Result of numerical modelling shows that reinforced pastefill after 28 days curing time is in stable condition. Therefore it can be suggested that mining operation underneath pastefill with 14% of cement content can be carried out after 28 days of pastefill placing.

INTRODUCTION

PT Nusa Halmahera Minerals (NHM) is mining company which is located in Gosowong, North Halmahera, North Maluku Province, Indonesia as can be seen in Figure 1. One of NHM mine site is Kencana Underground Gold Mine.

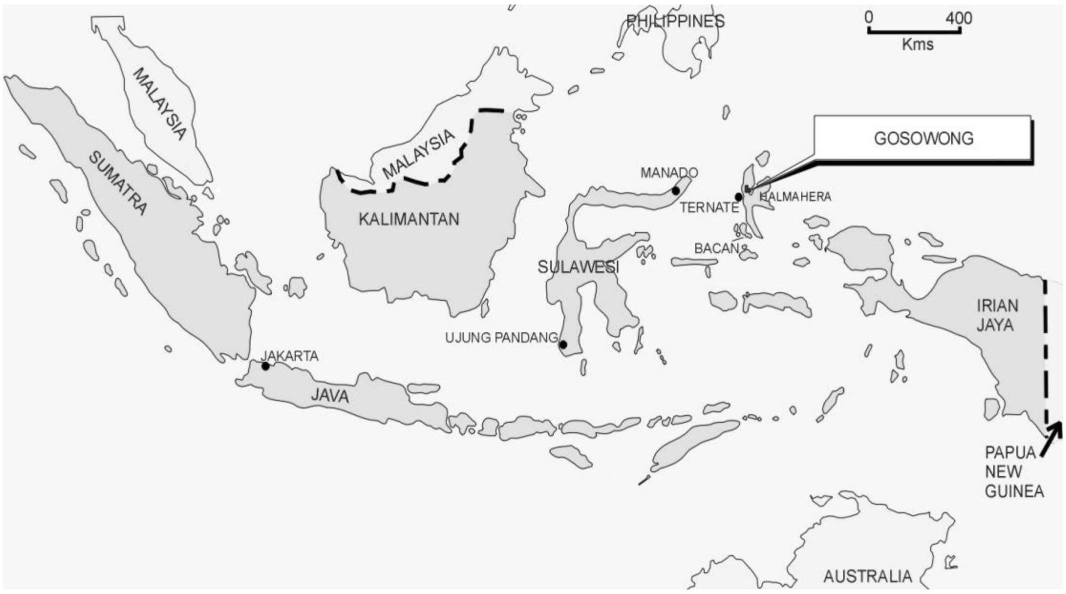

Figure 1: Kencana Underground Gold Mine Location

NHM has operated open pit mine at Gosowong and Toguraci area. Mining operation at both area is extended by underground mining method. The Kencana underground mine which extension of Gosowong Open Pit located approximately 1 km southern side of Gosowong open pit. One of mining method applied in Kencana Underground gold mine is Underhand Cut and Fill (UCF) mining method. The UCF is chosen due to high recovery rate and safety reason. The UCF method is more secure than other underground mining method when dealing with poor rock conditions (Williams, 2006). However, its backfill material should be paid in attention because it will act as back (roof) when underneath stope is opened (Williams, 2006; Pakalnis, 2005). In this area pastefill type is used for backfill material. Therefore, stability analysis of pastefill block needs to be carried out. This research is conducted in Kencana-2 Sub 12 C undercut 3 Ore Drive (OD) 1 North Vein which is located 305 m below the surface. Pastefill stability analysis is carried out by applying numerical analysis using 3DEC software ver. 2 from ITASCA and analytical analysis using limit equilibrium equation.

RESEARCH METHODOLOGY

This research is begun with field study which consist of literature study and data collection such as geometry of ore vein and underground opening, mine planning map, physical and mechanical properties of rocks in research area, and backfilling process. Then it is continued by laboratory test to obtain physical and mechanical properties of pastefill at Geomechanics and Mine Equipment Laboratory ITB and Geomechanics Laboratory of Puslitbang Tekmira Bandung. After laboratory test is conducted, desk study for analyzing the stability of pastefill block by conducting numerical analysis and analytical analysis.

GEOLOGY OF KENCANA VEIN AREA

The average dip of Kencana Utama Vein (K1) is 45^0 with north east dip direction. Vein length in striking direction based on exploration carried out by NHM is 400 m and in Down-dipping direction is 300 m. Exploration activity is still carried out to discover vein extension to north direction and also to south direction. Kencana Vein (K2) is located in southwest of Kencana Utama Vein (K1). Both vein is predicted as extension of Gosowong vein in southern direction. K2 is interpreted as vein that parallel with K1 mineralization and has similar orientation. (NHM, 2006)

Figure 2: Kencana Gold Veins Map (NHM, 2006)

K2 Vein is formed in the host rock dominated by andesitic and volcaniclastic rock. Au-Ag-rich mineralization in K2 vein (identified through drillhole core sample) striking length is approximately 150 meter and dipping length approximately 150 meter. K2 Vein geometry in general has thickness varies from 10 – 50 m and orientation (Strike/Dip) of N 350^{o}E/50^{o}NE.

MINING METHOD

Underhand Cut and Fill (UCF) is one of mining method used in Kencana Vein (K2). Schematic of UCF method can be seen in Figure 3 (Williams, 2006).

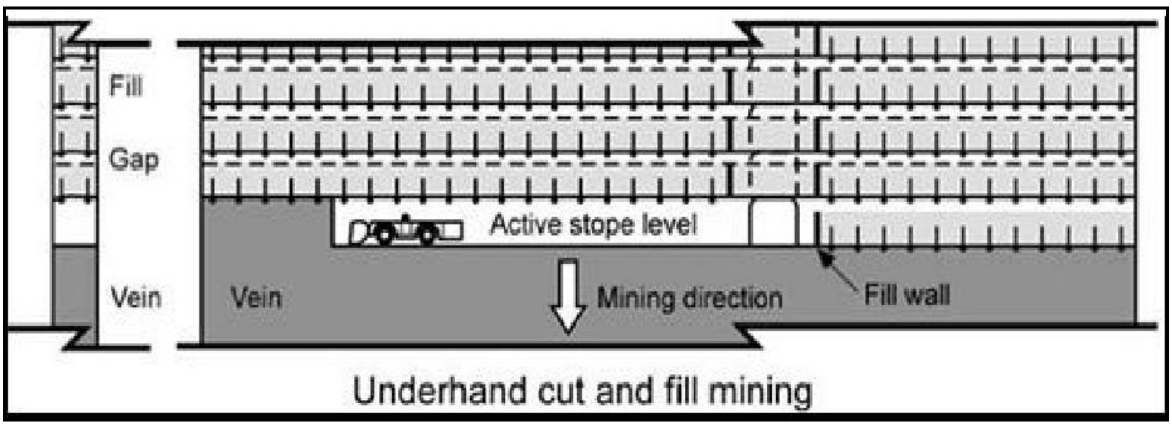

Figure 3: Schematic of Underhand Cut and Fill Mining Method (Williams, 2006)

By applying this method, mining activity at vein is carried out per slice from top to bottom so that it is more secure when mining is carried out at poor rock condition. This research is conducted in Kencana 2 Sub 12C Undercut 3 Ore Drive (OD) 01 North as can be seen in Figure 4.

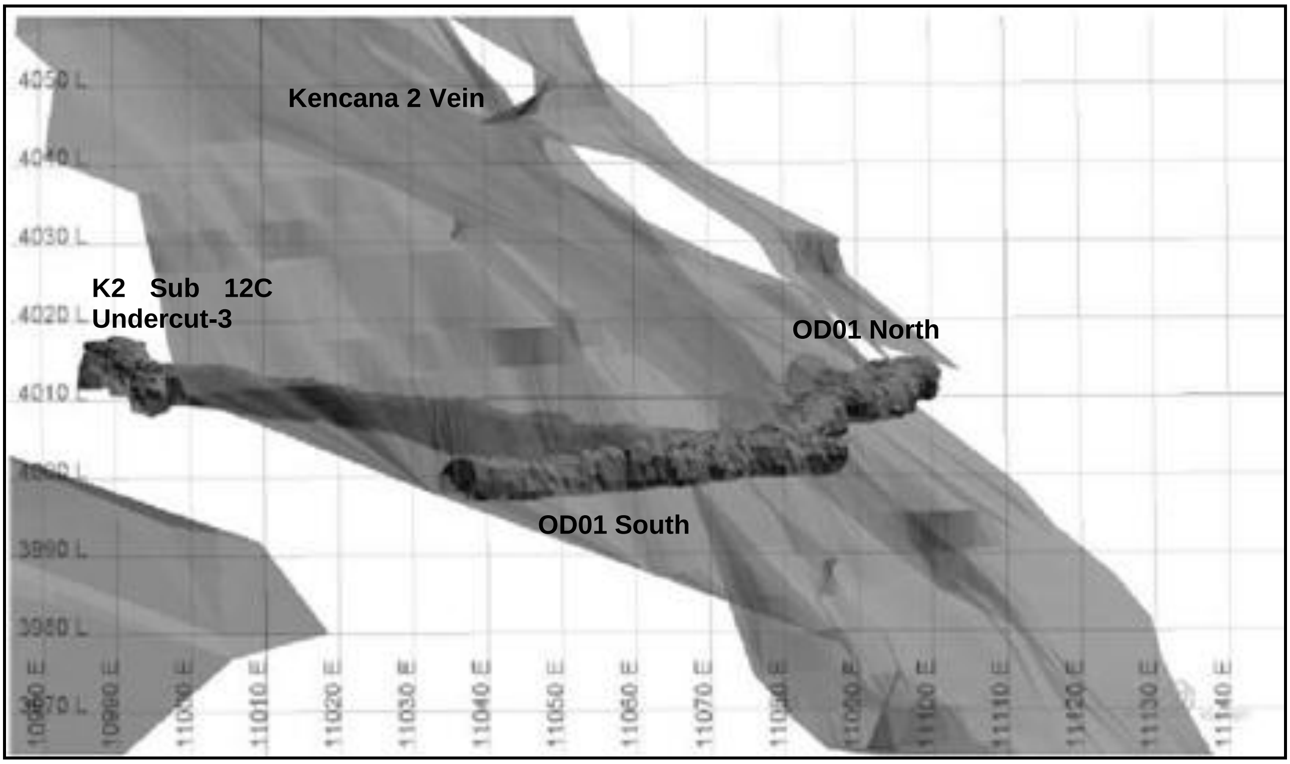

Figure 4: Kencana 2 Vein and Location of K2 Sub 12C Undercut 3 Ore Drive 01

DATA AND ANALYSIS

Vein Geometry and Pastefill

Based on the obtained data, geometry model of vein and pastefill is then constructed using the value given in Table 1 for the means of analysis (ITASCA, 1999).

Vein Geometry	Value	Stope and Pastefill Dimension	Value
Vein width	50 m	Ore drive width	6 m
Striking length	150 m	Ore drive heigth	5.5 m
width per ore drive	6 m	Ore drive length	40 m
Vein dip	500	Pastefill width	6 m
Vein strike	N 100 W	Pastefill heigth	5 m
Down dipping Length	200 m	Pastefill length	40 m

Table 1: Vein, Ore Drive, and Pastefill Geometry

Physical and Mechanical Properties of Rocks and Pastefill

Physical and mechanical properties from each material are obtained from secondary data based on rock samples tested by NHM as given in Table 2 and 3. Physical and mechanical properties of pastefill (made of tuff slurry with 14% cement content) which are resulted from test carried out at Geomechanics and Mine Equipment Laboratory ITB and Geomechanics Laboratory of Puslitbang Tekmira are shown in Table 4.

Type of Rock	γ (t/m^3)	σ_c (MPa)	E (GPa)	*v*	K (GPa)	G (GPa)
Andesite Hematite Clay (HW)	2.54	28.40	10.7	0.1	4.45	4.87
Breccia Andesite Quartz (Ore)	2.50	21.23	18.31	0.2	10.17	7.63
Breccia Andesite (FW)	2.52	29.01	20.31	0.2	11.28	8.46

Table 2: Physical and Mechanical of Rocks in Research Area

Plane of Contact	*C* (MPa)	Φ (^{0})	Kn (GPa/m)	Ks (GPa/m)
Ore - Hangingwall	2.22	35.5	1	0.2
Ore - Footwall	2.32	22	1	0.2
Pastefill – Ore (For Paste with 14% Cement of 7 Days)	0.086	28.679	0.1	0.02
Pastefill – Hangingwall (For Paste with 14% Cement of 7 Days)	0.086	28.679	0.1	0.02
Pastefill-Ore (For Paste with 14% Cement of 28 Days)	0.286	29.950	0.1	0.02
Pastefill-Hangingwall (For Paste with 14% Cement of 28 Days)	0.286	29.950	0.1	0.02

Table 3: Properties of Joint and Contact Planes for Numerical Modelling

Type of Pastefill Specimen	□ (t/m3)	σc (MPa)	E (MPa)	v	σt (MPa)
14% Cement of 3 Days	1.56	0.50	307.31	0.31	0.05
14% Cement of 7 Days	1.54	0.69	432.28	0.38	0.07
14% Cement of 14 Days	1.55	0.85	504.63	0.39	0.08
14% Cement of 28 Days	1.56	1.31	544.89	0.38	0.13

Table 4: Physical and Mechanical Properties of Pastefill

Pastefil Stability Analysis using Analytical Method

Types of pastefill failure which may occur following the failure mechanism proposed by Mitchell (Caceres, 2005) are caving failure, flexural failure, and sliding failure.

Caving Failure

Assuming that caving would extend to a stable arch height L/2 (for a semi-circular arc), all unreinforced pastefill block would form a thickness, t> L/2, and caving would occur when (Caceres, 2005):

$$L\gamma > 8\sigma_t / \pi \qquad (1)$$

Where :

σ_t = tensile strength of pastefill material

γ = unit weight of pastefill material

L = stope span

The driving forces represented by the weight *w* of the arc of radius *L*/2 are defined as :

$$w = \frac{\pi . L^2}{8} \gamma \qquad (2)$$

The safety factor (*SF*) is derived by the forces resisting movement over the driving forces :

$$SF = \frac{8\sigma_t}{\gamma \pi L} \qquad (3)$$

Flexural Failure

A wide, thin pastefill is susceptible to flexural failure due to the relatively low tensile strength of cemented pastefill. Using standard flexural formula for fixed-end uniformly-loaded beam, failure is predicted when (Caceres, 2005):

$$\left(\frac{L}{t}\right)^2 > \frac{2(\sigma_t + \sigma_h)}{w} \text{ or } \left(\frac{L}{t}\right)^2 > \frac{2(\sigma_t + \sigma_h)}{\sigma_v + d\gamma} \qquad (4)$$

Where :

σ_t = tensile strength of pastefill material

σ_h = Horizontal confining stress

w = uniform loading, which include the self-weight of the pastefill

t = pastefill block thickness

L = stope span

Provided that $\sigma_h = \sigma_v = 0$, safety factor for flexural failure can be calculated using the following equation :

$$SF = 2\sigma_t t / \gamma L^2 \qquad (5)$$

Sliding Failure

From equilibrium state, pastefill block sliding will occur as a result of side shear failure when (Caceres, 2005) :

$$(\sigma_v + t\gamma) > 2\left(\frac{\tau_t}{\sin^2(\beta)}\right)\left(\frac{t}{L}\right) \qquad (6)$$

Provided that $\sigma_v = 0$, Safety factor for sliding failure can be calculated using the following equation :

$$SF = 2\tau_t t / L \sin^2 \beta \qquad (7)$$

Where :

σ_v = vertical confining stress

σ_t = tensile strength of pastefill material

σ_h = Horizontal confining stress

τ_t = Shear strength of pastefill material

γ = unit weight of pastefill material

t = pastefill thickness

L = stope span

β = stope angle

The result of calculation to identify potential failure mechanism that may occur on pastefill block based on equation 1-7 is then plotted in three curves shown in Figures 5 and 6. Figure 5 shows the pastefill block SF due to various opening span for 7 days curing time pastefill while Figure 6 shows the SF for 28 days curing time pastefill. These safety factor is calculated based on assumption that zero vertical confining stress condition due to the existing gap at the above pastefill block and zero horizontal confining stress condition due to no horizontal deformation from footwall/highwall rock as a conservative approach.

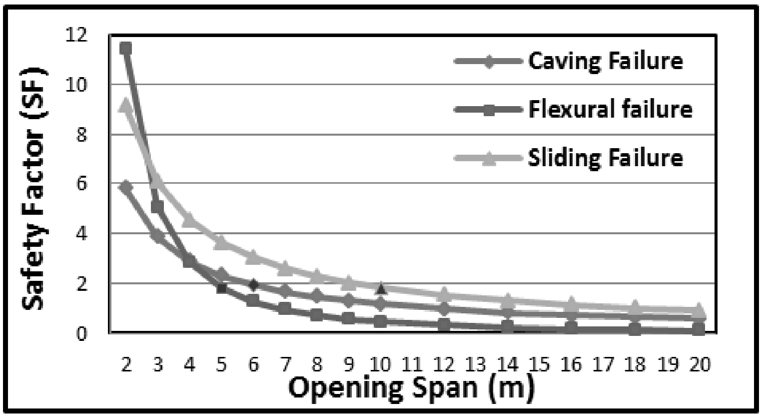

Figure 5: Curve of safety factor vs. span variation for 7 days curing time pastefill

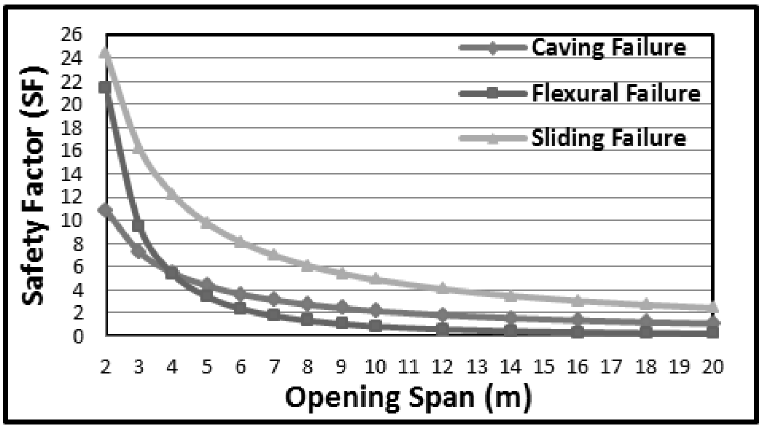

Figure 6: Curve of safety factor vs. span variation for 28 days curing time pastefill

Numerical Modelling

Numerical modeling is carried out for analyzing the stability of pastefill block with 7 and 28 days curing time. The result of 7 days curing time pastefill model is given in Figures 7 and 8 while for 28 days curing time pastefill model is given in Figures 9 and 10. Both pastefill models are failure as shown by y-displacement curve obtained from selected monitoring point in pastefill model which are not stable until the end of calculation.

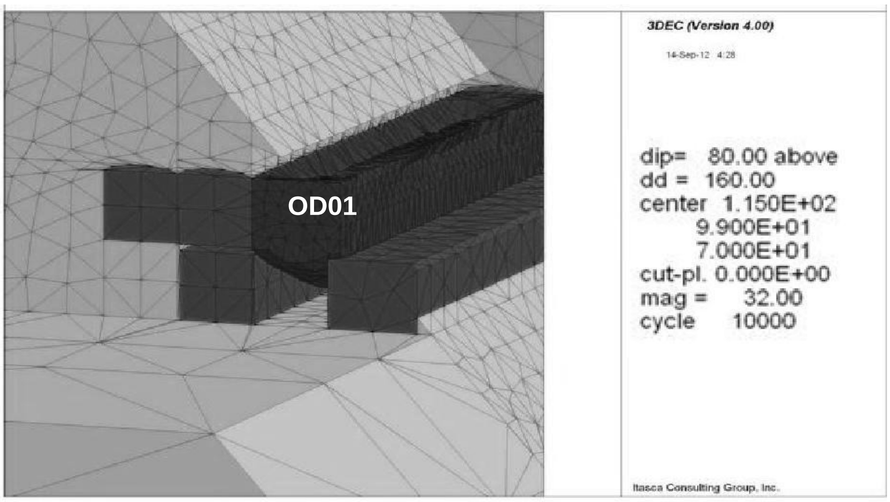

Figure 7: Deformed model of 7 days curing time pastefill

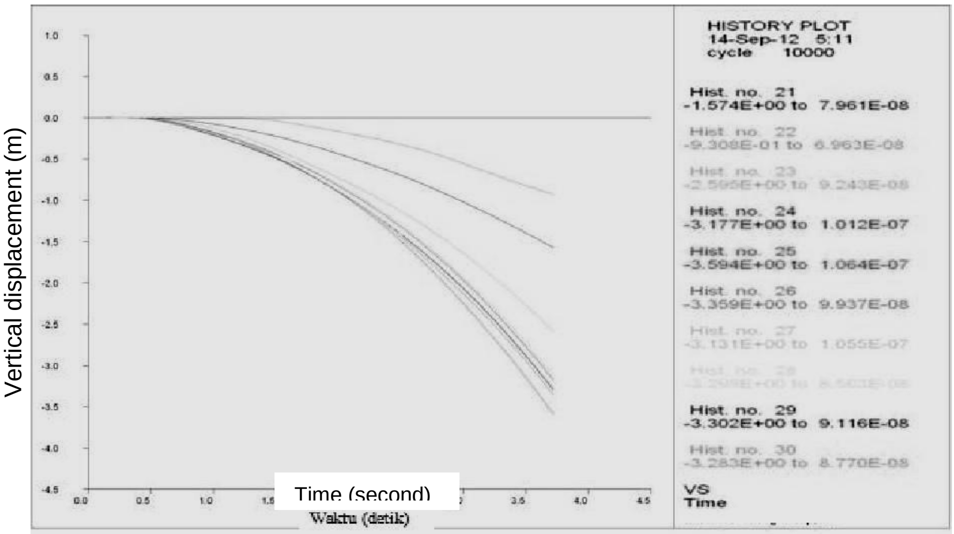

Figure 8: y-displacement curve from model of 7 days curing time pastefill

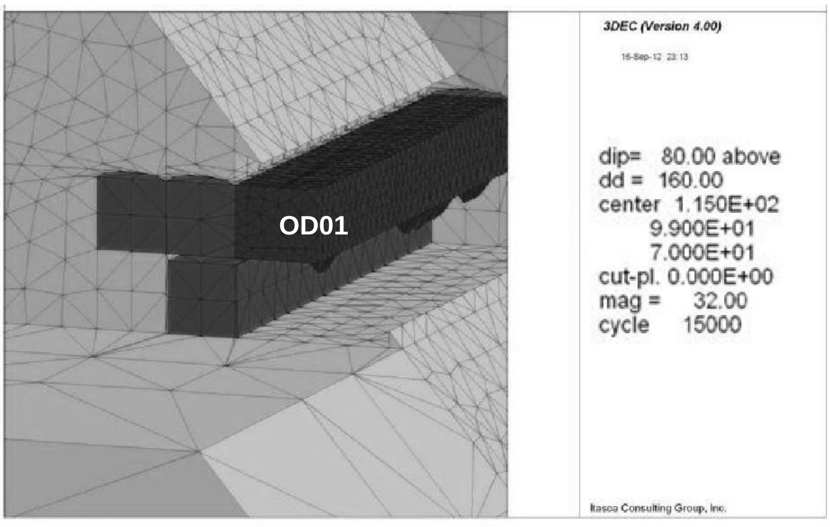

Figure 9: Deformed model of 28 days curing time pastefill

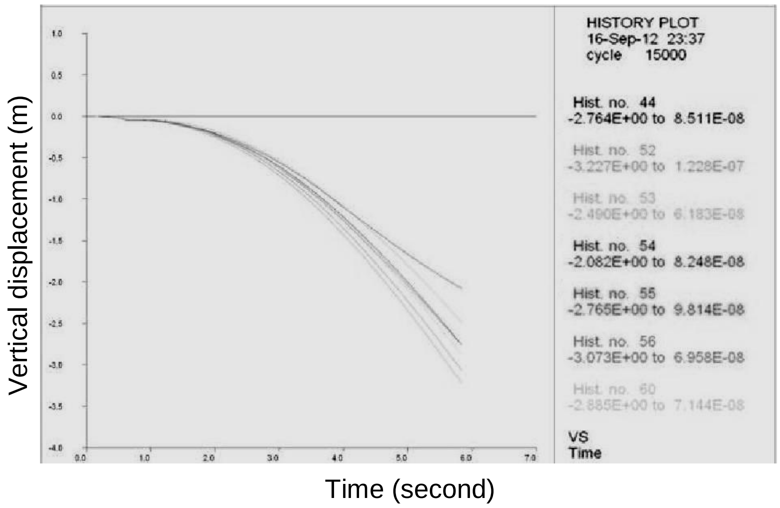

Figure 10: y-displacement curve from model of 28 days curing time pastefill

To prevent the failure that may occur based on numerical analysis, reinforcement is then given (Pakalnis, 2005) by installing chain link mesh and stand up bolt at the floor of mined out stope before the stope is filled by pastefill as can be seen in Figure 11. The result of calculation using the reinforced pastefill model is shown in Figures 12-15. From those Figures, it can be seen that 7 days curing time pastefill is still unstable while 28 days curing time pastefill is in stable condition (Figures 15).

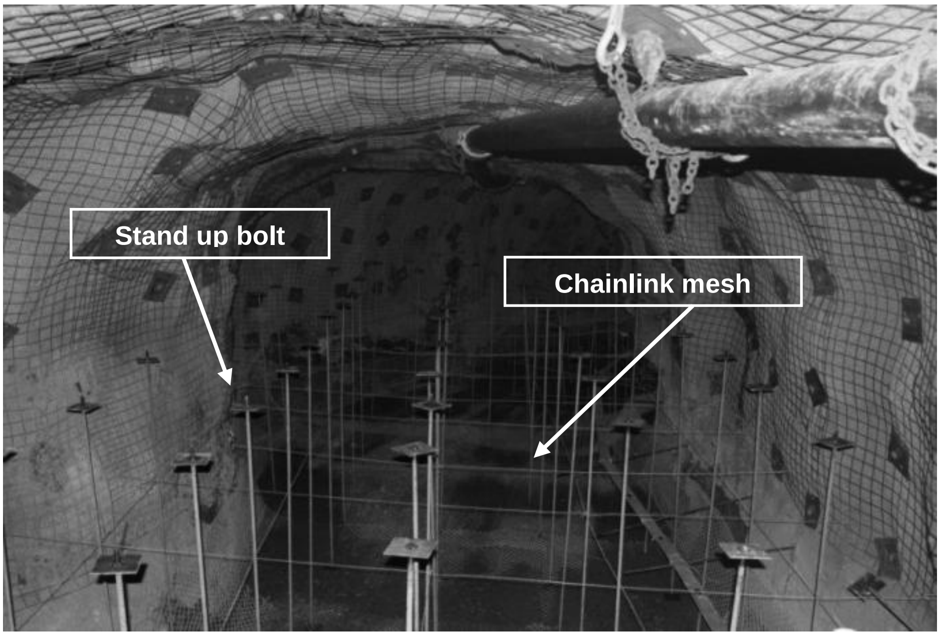

Figure 11: Installation of pastefill reinforcement

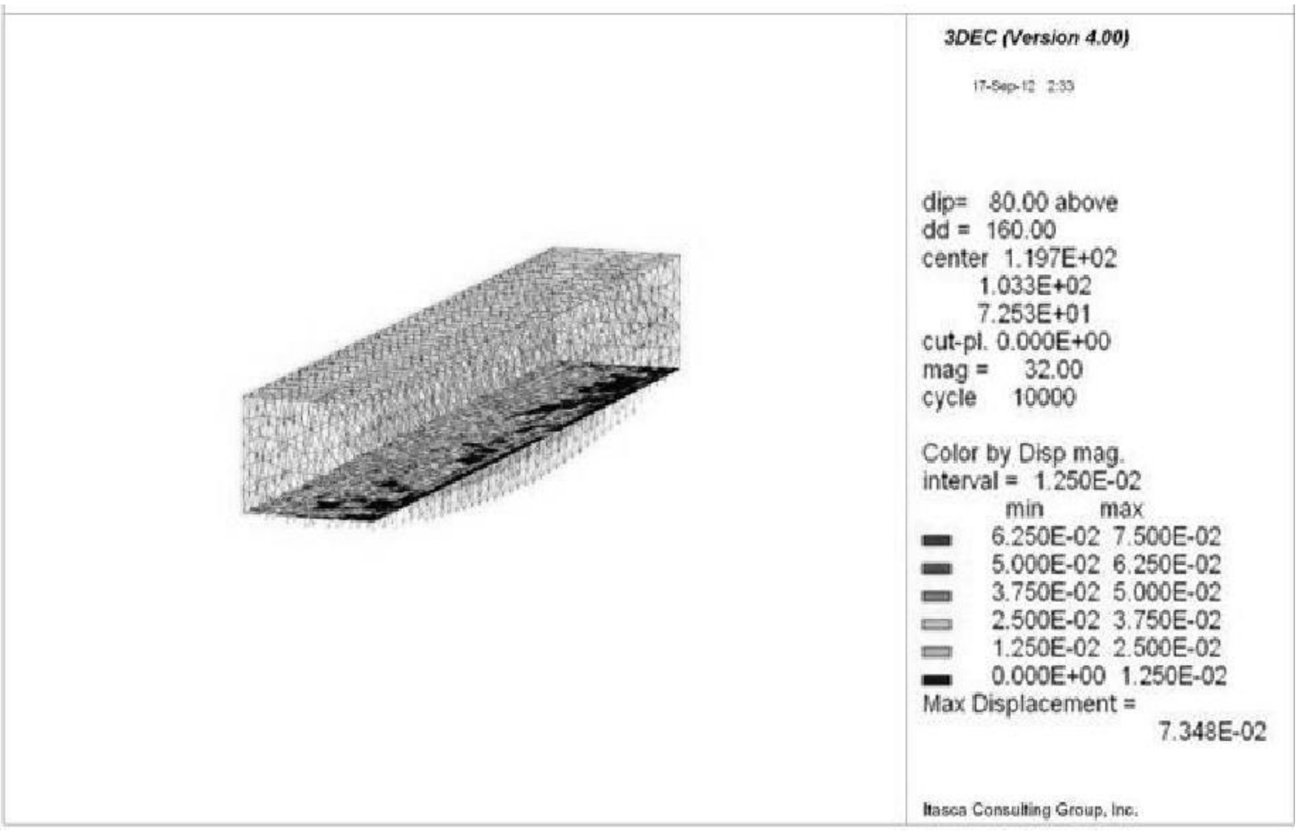

Figure 12: Deformation of 7 days curing time reinforced pastefill block

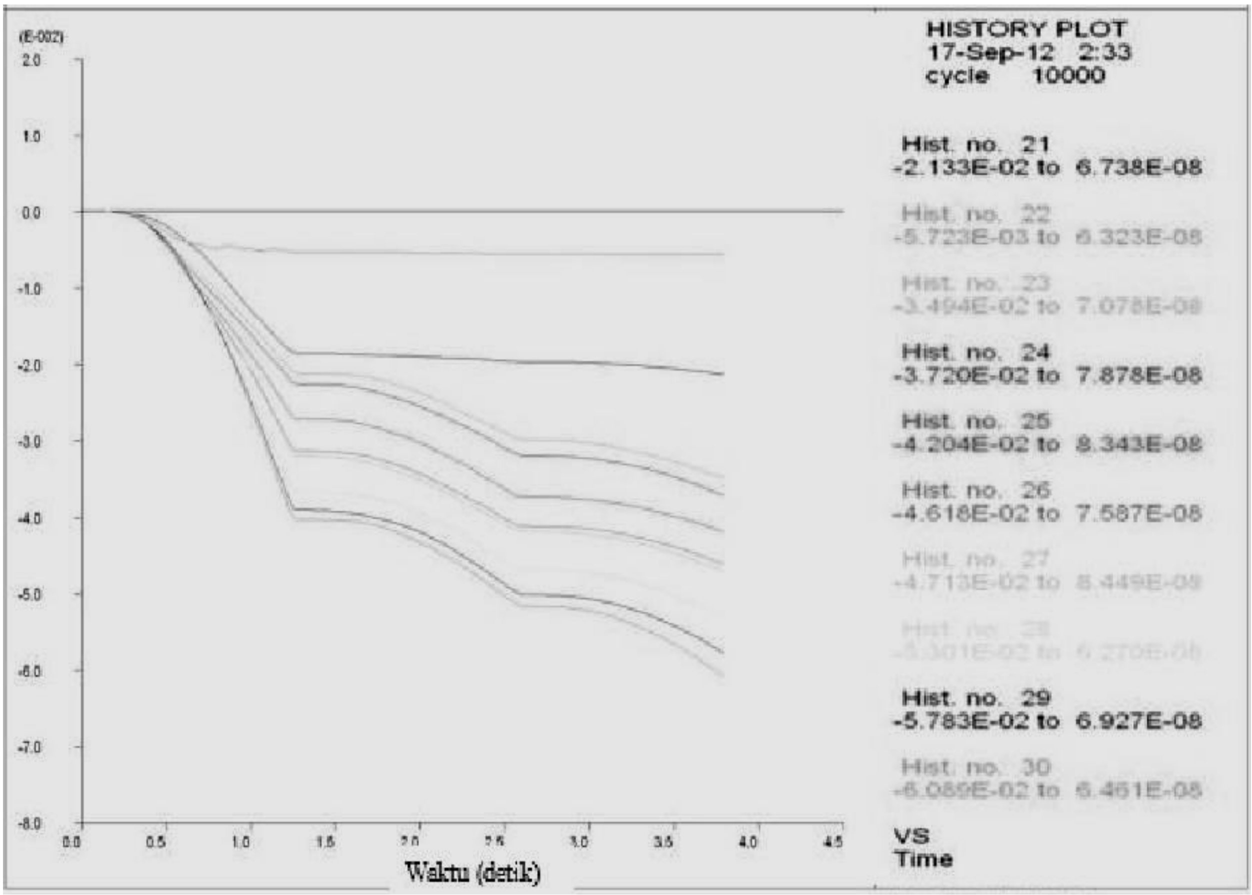

Figure 13: y-displacement of 7 days curing time reinforced pastefill block

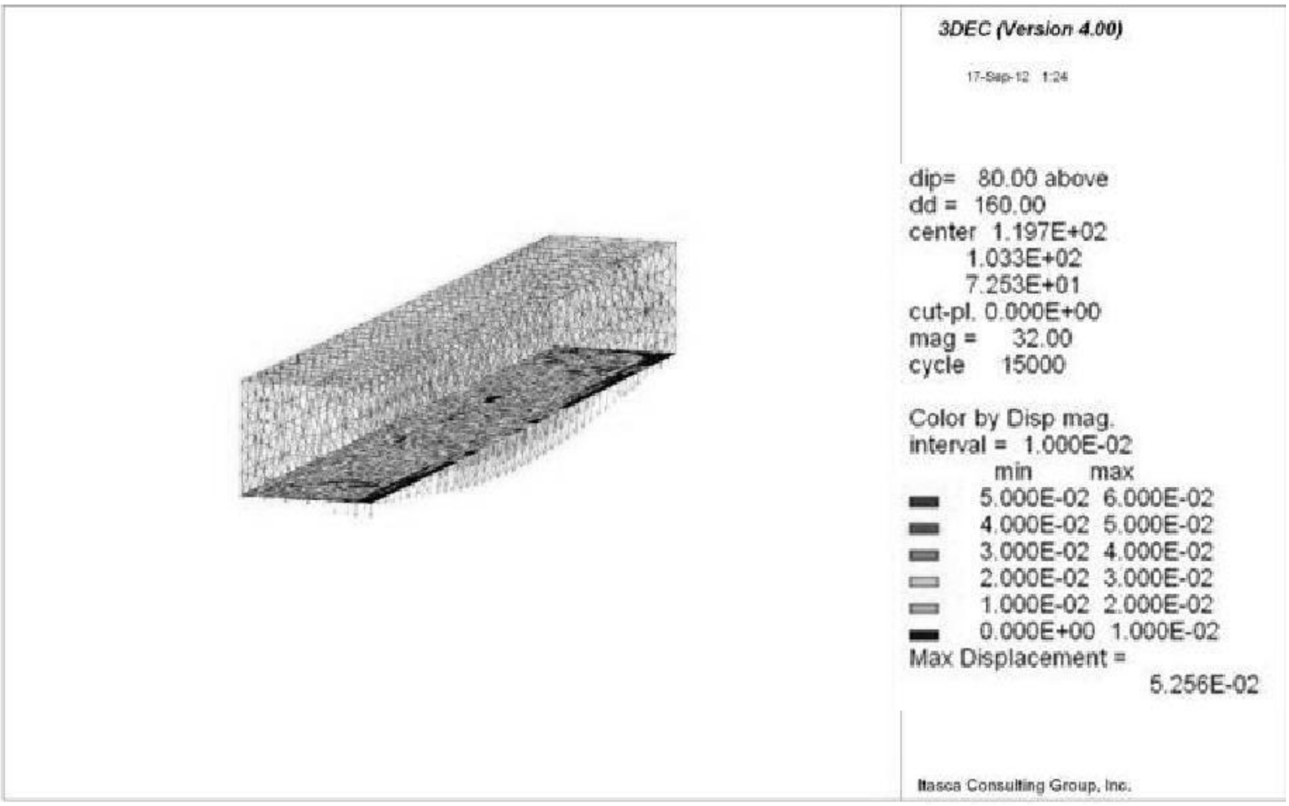

Figure 14: Deformation of 28 days curing time reinforced pastefill block

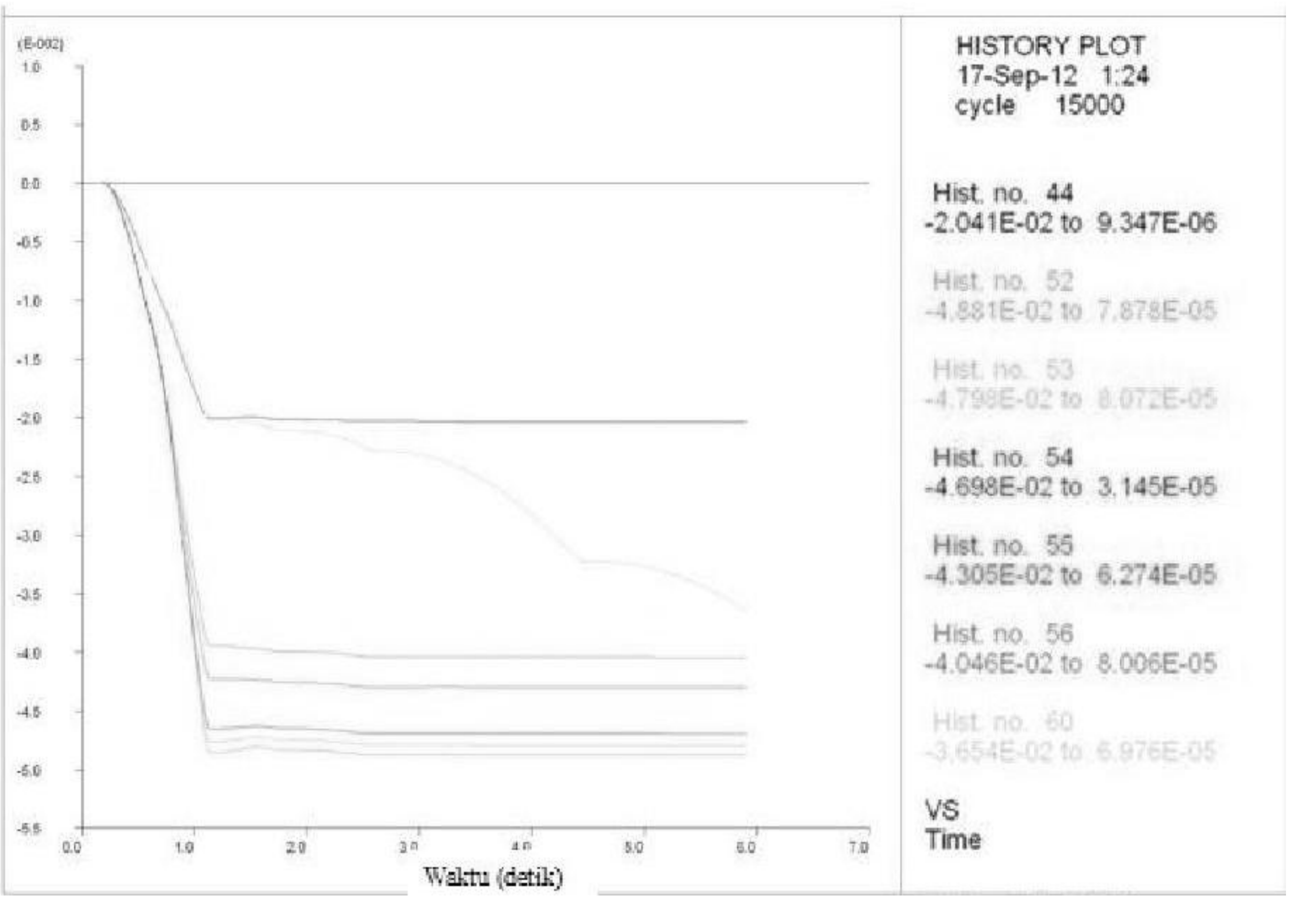

Figure 15: y-displacement of 28 days curing time reinforced pastefill

DISCUSSION

Figures 5 and 6 shows the relationship between safety factor and variation of opening span below the pastefill block. It can be seen that safety factor will increase as the curing time increase because pastefill material will become stronger over the time. From the analysis it can be seen that opening span design which is allowed (SF ≥ 2) to carry out mining activity below pastefill with 14% cement content is around 5-6 meter. And it can also be seen that mining activity can be carried out using 28 days curing time pastefill, eventhough caving failure or flexural failure is still potentially occur (Figure 9).

From numerical modeling result, unreinforced pastefill with 14% cement content, for both 7 and 28 days curing time, is in unstable condition. Based on the shape of deformation occur at both pastefill block, the failure will occur at the bottom side of the block. This failure type is similar with the type of failure predicted by analytical analysis which is caving failure. Based on calculation using equation 1, this kind of failure will occur at opening span ≥ 6 meter, and this result also confirmed by numerical analysis which is shown that at 6 meter span caving failure will occur.

After reinforcement is given to the pastefill block, result of analysis shows that 7 days curing time pastefill is still in unstable condition as shown in Figure 13 that the y-displacement curve from the selected monitoring point at the bottom of pastefill block still moving over the time. In contrary, for 28 days curing time pastefill is in stable condition with maximum y-displacement occurs in the bottom of pastefill block is 5 cm as shown in Figures 14 and 15. Therefore, it can be concluded that 28 days curing time pastefill with reinforcement is in stable condition and mining activities can be carried out below it. This condition has been already confirmed by actual field condition. Figure 16 shows the condition of stope which opened below the reinforced pastefill block after reaching 28 days curing time. The 28 days curing time pastefill will reach its strength due to the curing process, and its UCS value obtained from laboratory test is 1.31 MPa which has fulfill the strength criteria from NHM which is 1.20 MPa.

Figure 16: 28 days curing time Pastefill block with reinforcement

CONCLUSIONS

From this research it can be concluded that unreinforced pastefill block with 14% cement content for both 7 and 28 days curing time is in unstable condition. However by reinforcement, 28 days curing time pastefill block with 14 % cement content can be applied as backfill material. The analytical analysis result is also in a good agreement which opening span of a 6 meter can be carried out after pastefill block reaching 28 days curing time. Therefore it can be suggested that mining activity is able to be carried out beneath reinforced pastefill block with 14 % cement content after reaching 28 days curing time.

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