Stability Analysis of Pastefill Used in Underground Gold Mining by Underhand Cut and Fill Method in The Kencana Halmahera Island - Indonesia

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ABSTRACT

PT Nusa Halmahera Minerals (PT.NHM) is a gold mining company which operating in the Kencana–Gosowong, North Halmahera Regency, North Maluku Province-Indonesia. From the evaluation results, Underhand Cut and Fill method (UCF) has been chosen because of several considerations, among others, low cash flow, high recovery, and more secure in the face of poor rock conditions. But the problem that must be faced is about the stability of pastefill that act as a roof for workers and mine equipment below. Then the location will be focused of this research is Kencana-1 Sub 12C Undercut 3 Ore Drive 1 North. In analyzing the stability of pastefill is used of two approaches, the numerical modeling with distinct element method use of software 3DEC Version 2.0 from Itasca and analytical approach with use of limit equilibrium method. Physical and mechanical properties of rocks obtained from PT. NHM and pastefill properties obtained from Tekmira Geomechanics Laboratory testing in Bandung. From the results of this numerical modeling, pastefill with 14% cement content with 7 and 28 days curing time would collapse with the mechanism of caving failure on 6m of span and it is appropriate with the limit equilibrium calculation that mechanism of caving failure will occur in 6m of span. To solve the instability of these pastefill, the chain link mesh is installed on the bottom of the stope opening before the stope filled. Based on numerical modeling results, that is indicate pastefill with 7 days curing time remains unstable with the installation of chain link mesh and stand up bolt, while pastefill with 28 days curing time is more stable and obtained UCS value 1.31 MPa, has full fill condition of 1.2 MPa. Then the mining under pastefill with 14% cement content can be carried out at age of 28 days. UCS design of pastefill is matched with the short term and long term mine planning, in relation to the strength of cement mix design within time required to mine, either beside or below it.

1. INTRODUCTION

Kencana underground gold mining done by PT. Nusa Halmahera Minerals (PT.NHM) which is a gold mining company operating in the Gosowong-Halmahera Island in Indonesia (Figure 1.1).

Figure 1.1. Location map the gold fields Gosowong on a scale map of Indonesia

Initially the company was mining with open pit method in the Gosowong and Toguraci gold mine, then did the expansion of the mine area with a system of underground mining in the Kencana area is ± 1 km to south Gosowong and Toguraci area is ± 3 km to west Gosowong. From the results of evaluation of the technical feasibility, underhand cut and fill method (UCF) and the long hole stope (LHS) selected for considerations include ; the cash flow is low, high recovery, technical mining safer when dealing with poor rock conditions. The study was conducted at the location of Kencana-2 Vein Sub 12C UC3 OD01 North with underhand cut and fill mining method. Position of the location at 305m depth of below the ground surface. But the problems that must be faced is the stability of backfilling material that acts as a kind pastefill roof for workers and tools are below. For that conducted a study on the pastefill stability with a numerical modeling approach using 3DEC Version 4.0 of Itasca software and analytical approach using limit equilibrium equations (Mitchell, 1991).

2. METHODOLOGY OF RESEARCH

This study aims to analyze the stability of pastefill and know the type of failure that occurred. The study starts from the formulation of the problem, the study of literature, data collection as such ; a map of mine planning, the ground opening geometry, physical and mechanical properties of rocks at the site, and testing the physical and mechanical properties of pastefill materials in the Geomechanics Laboratory of ITB and Geomechanics Laboratory of TEKMIRA. Proceed with numerical data processing using 3DEC Version 4.0 from Itasca and analytical calculations with used limit equilibrium equations to calculate the pastefill stability (Mitchell, 1991). Then do the analysis and discussion of the results of both approaches. Once it can be concluded about the pastefill stability in the location of Kencana-2 Vein Sub 12C UC3 OD01 North.

3. GEOLOGICAL OF KENCANA VEIN

Kencana vein is average slope of 45^0 to the East Grid or NNE magnetic. The length of the structure is known until now about 400m (19650mN to 20050mN). Forwarding to the slope (down-dip) of about 300m and is still open at depth. Based on data from drilling, mineralization to the North is still not evident stops but obviously still open to the South and to the inside. Kencana-2 Vein (K2) is located in the South-West veins main Kencana (K1) in the Southern part of the block Gosowong Extended. Kencana-2 vein is interpreted as an almost parallel with the mineralization of Kencana-1 vein and have a similar orientation, with an average slope of 45^0 to the Northeast.

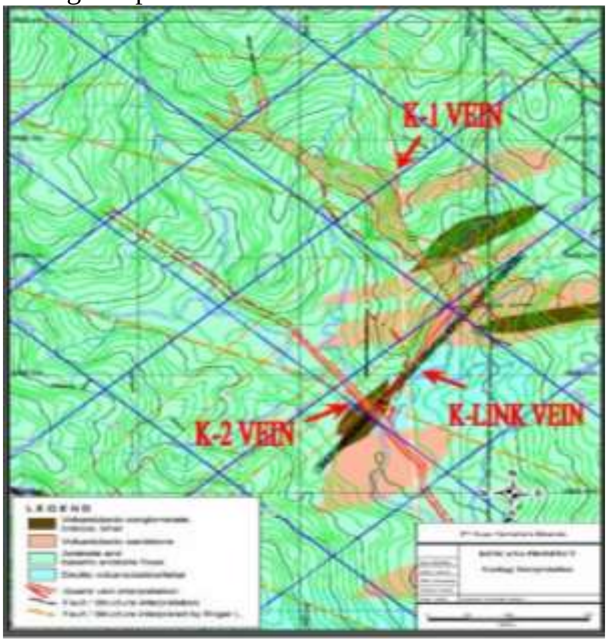

Figure 3.1. Map of Kencana gold veins and Interpretation Surface Geology (Source:PT NHM, 2012)

K2 vein found in the predominantly andesitic rocks and vulcanoclastic which is also the presence of K1 and mineralization of Gosowong. Au-Ag mineralization is high grade veins across by drill hole K2 on that basis with a distance of approximately 150m and 150m depth followed dip. Vein geometry of Kencana-2 that the slope of the vein to deliver the depth of 150 m, thickness varies are 10-50m, width of the strike 150-200m and ore dip/Strike are 50^0 NE/N 350^0 E.

4. MINING METHODS

Technically and economically, have evaluated the 5 (five) mining method as follows ; Open Pit, Underhand Cut and Fill (UCF), Overhand Cut and Fill (UCF), Caving method, and Long Hole Stope (LHS). Of several alternative mining methods were evaluated finally decided to Kencana mine done by combinations Underhand Cut and Fill Mining and Long Hole Stope Methods. In this study only concentrated on the underhand cut and fill mining methods are illustrated in Figure 4.1 below.

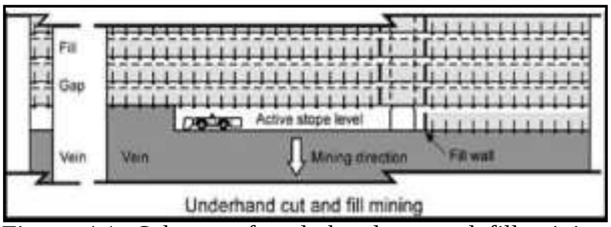

Figure 4.1. Scheme of underhand cut and fill mining method

The most fundamental in the application of the method of UCF is high recovery, and mining from top to bottom. This method has been recognized as the best method that allows production activities take place safer than other methods on the condition of the poor rock. The location are then the focus research of the underhand cut and fill methods is Kencana-2 vein Sub 12C Undercut 3 Ore drive 01 North as shown in Figure 4.2 below.

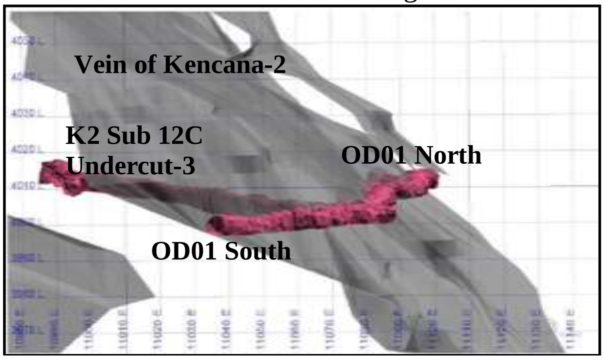

Figure 4.2. Model of Kencana-2 Vein Sub 12C Undercut 3 Ore Drive 01

5. DATA AND DATA PROCESSING

5.1. GEOMETRY VEIN AND PASTEFILL

To create a model that can represent the actual situation on the ground, the stope geometry measurement aperture to used as input for the model to be made. Geometry measurements include the dimensions of openings (strike length of veins, width and height), the orientation of the excavation, as well as the orientation of the orebody (strike/dip). Backfill dimensions (strike length toward the stope, width and height). Here are the data used to define the geometry of the model in Table 5.1.

Tabel 5.1. Data of Geometry vein, ore drive and pastefill

Vein Geometry	Value	Stope and Pastefill Dimension	Value
Vein width	50 m	Ore drive width	6 m
Strike length	150 m	Ore drive heigth	5.5 m
Thickness per ore drive	5-6 m	Ore drive length	40 m
Vein dip	50^0	Pastefill width	6 m
Vein strike	N 10^0E	Pastefill heigth	5 m
Length of dip	200 m	Pastefill length	40 m

5.2. PHYSICAL AND MECHANICAL PROPERTIES OF ROCK AND PASTEFIL

The physical properties of rocks at the site and pastefill include ; density, water content, porosity, and others. While the mechanical properties include compressive strength (UCS), tensile strength, modulus of elasticity, Poisson's ratio, angle of friction and cohesion. For the planes contact (interface or joints) properties data is needed ; cohesion, friction angle in contact, normal stiffness and shear stiffness of the contact area. Physical and mechanical properties of each material at the location based on secondary data obtained from rock samples that have been tested previously and most do their own testing in Geomechanics Laboratory Institute of Technology Bandung (ITB). (see Tables 5.2, 5.3 and 5.4).

Table 5.2. Physical and mechanical properties of rocks in the research location.

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 Quarzt (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

Tabel 5.3. Properties of joint and contact planes for input data numerical modeling

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
Pastafill – 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 5.4.Physical and mechanical properties of pastefill

Type of Pastefill Specimen	γ (t/m^3)	σ_C (MPa)	*E* (MPa)	v	σ_t (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

5.3 ANALYTICAL METHOD OF PASTEFILL STABILITY

The types of pastefill failure that may occur, according to Mitchell 1991, in the limit equilibrium equations include Caving Failure, Flexural Failure, and Sliding Failure. Will be briefly described below:

Caving Failure

Is widely assumed to caving failure to a high stability against arch *L/2* (for a semicircular arch), no reinforcement all of the paste backfill are formed at a depth $d > L/2$ (Mitchell, 1991) and caving failure will occur when ;

$$L.\ \gamma > 8.\ \sigma_t / \pi \qquad (5.1a)$$

Forces that work as a driver is present by its own weight (w) of the arch radius L / 2 are defined ; $w = ((\pi.L^2)/\ 8).\gamma$. Tensile strength of backfill (σ_t), exceeds the width of the span (L) entirely from hangingwall to footwall with the presence of anchoring forces. The safety factor is obtained from the forces that resist movement with the forces that move the blocks namely :

$$FS = (8.\ \sigma_t) / (\gamma.\pi.L) \qquad (5.1b)$$

Flexural Failure

Pastefill of flexural failure easily if low tensile strength of pastefill. Flexural failure can be predicted as (Mitchell, 1991) :

$$\left(\frac{L}{d}\right)^2 > \frac{2.(\sigma_t+\sigma_h)}{w} \quad \text{or} \quad \left(\frac{L}{d}\right)^2 > \frac{2.(\sigma_t+\sigma_h)}{\sigma_v+d.\gamma} \qquad (5.2a)$$

While the value of the safety factor for flexural failure can be calculated by the formula (Sulistianto, 2012) :

$$FS = 2.\ \sigma_t\ .\ d / \gamma.\ L^2 \qquad (5.2b)$$

Sliding Failure

Based on the limit equilibrium method, block pastefill will slip / slide as a result of the friction of the wall of rock - pastefill, where the sliding failure will occur when (Mitchell, 1991) :

$$(\sigma_v + d.\gamma) > 2.\left(\frac{\tau_t}{sin^2(\beta)}\right).\left(\frac{d}{L}\right) \qquad (5.3a)$$

While the value of the safety factor for sliding failure can be calculated by the formula (Sulistianto, 2012) :

$$FS = 2.\tau_t\ .d / L.sin^2\ \beta \qquad (5.3b)$$

Description : σ_v = vertical load of pastefill above the sill (MPa), τ_t = pastefill shear strength (MPa), γ = density of pastefill (ton/m^3), L = span width stope opening (m), d = High or pastefill thickness (m), β = slope angle of the stope (^{0}), σ_t = pastefill tensile strength (MPa), σ_h =horizontal pastefill confining stress (MPa).

The results of calculation of the potential mechanisms of failure through equations 5.1 to 5.3 can be seen in the graph below. Figure 5.1 is an interpretation of results of the calculation of the safety factor with span width for 7 days pastefill age, and Figure 5.2 is an interpretation of results of the calculation of the safety factor with span width for 28 days pastefill age. The graph shows the correlation factor of safety against a wide variety of stope openings or span with zero horizontal and vertical stress caused by the absence of pressure from the rocks above and beside block of pastefill.

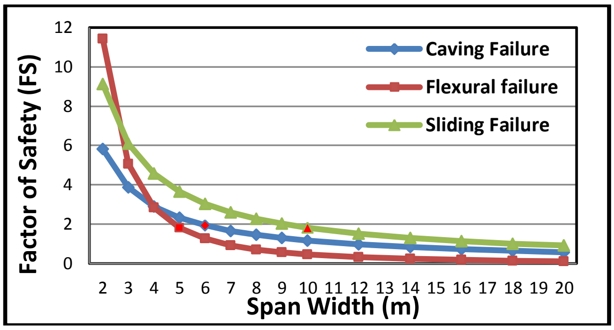

Figure 5.1. Curves relations safety factor and span width for 7 days age of pastefill

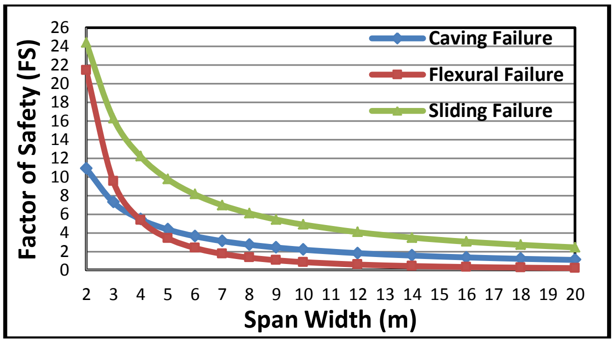

Figure 5.2. Curves relations safety factor and span width for 28 days age of pastefill

5.4. NUMERICAL MODELING

Numerical modeling was done to see stability pastefill visual material in accordance with the conditions on the ground. Modeling done to block pastefill with curing time 7 days and 28 days. Modeling results showed the two blocks with different curing time together will failure (see Figure 5.3, 5.4, 5.5 And 5.6.)

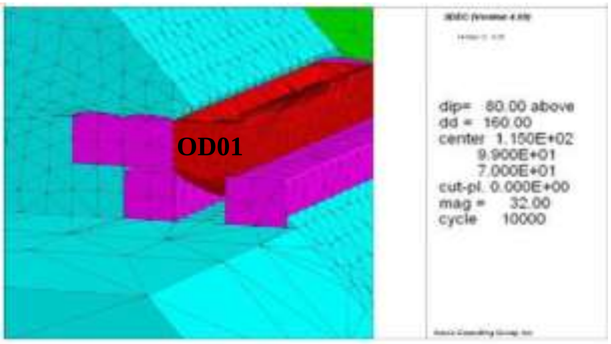

Figure 5.3. Failure type of pastefill block for 7 days curing time

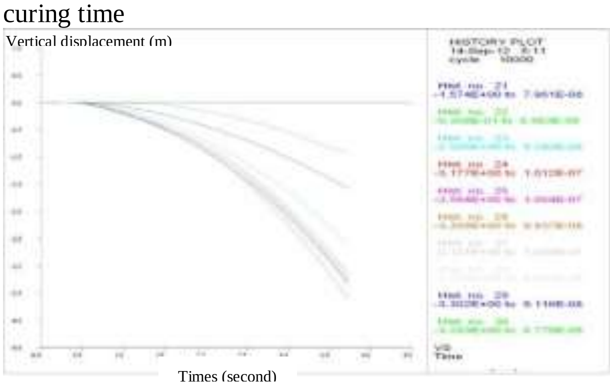

Figure 4.4. Y-displacement curve of pastefill block for 7 days curing time.

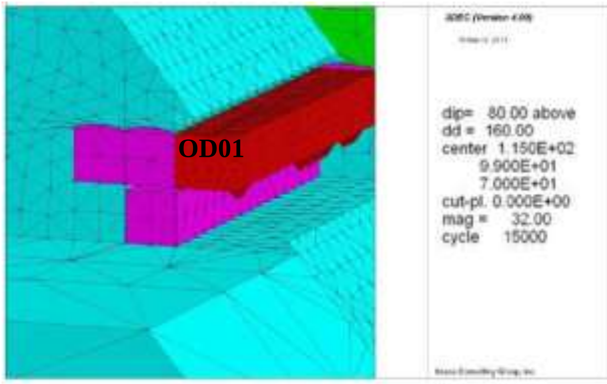

Figure 4.5. Failure type of pastefill block for 28 days curing time.

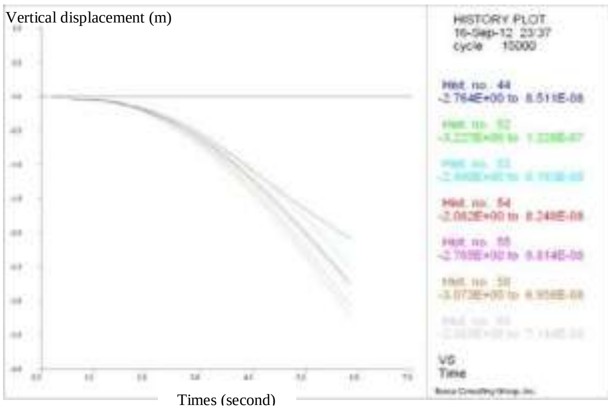

Figure 4.6. Y-displacement curve of pastefill block for 28 days curing time.

In pastefill block that acts as a roof for the opening underneath, towards the Y-displacement values obtained range 1.574m to 3.594m for 10000 cycle and 7 days pastefill age. Similarly, the Y-displacement values obtained range 2.082m to 3.227m for 15000 cycle and the pastefill age of 28 days, and indicate this pastefill block will movement on down to undergo to failure. To anticipate the failure that would happen, then the block pastefill given reinforcement by installation of chain link mesh and stand up bolt on the bottom of the OD1 stope openings before charging of pasta as shown in Figure 5.7. From the results of numerical modeling of pastefill with reinforcement is shown in Figure 5.8, 5.9, 5.10 and 5.11.

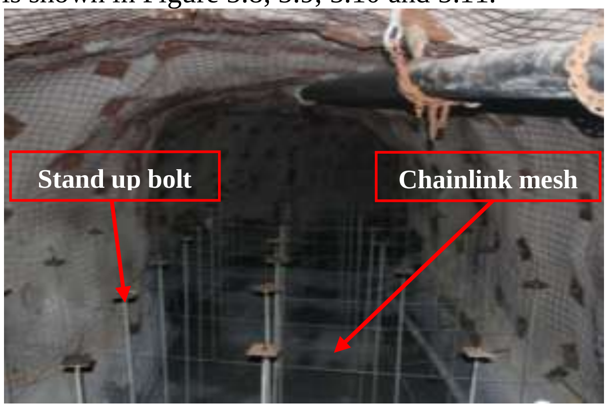

Figure 5.7. Pastefill reinforcement with the installation of chainlink mesh and stand up bolts before recharging.

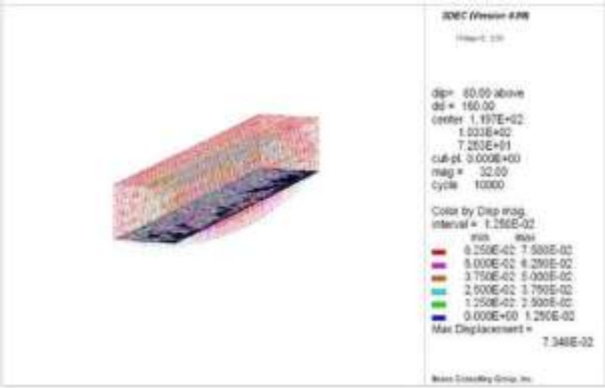

Figure 5.8. Failure type of pastefill block with reinforcement for 7 days curing time.

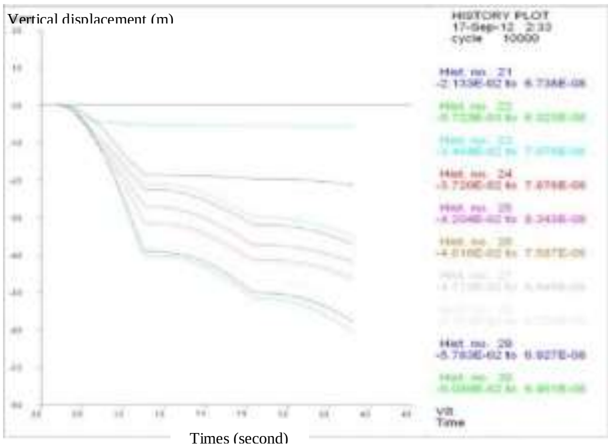

Figure 5.9. Y-displacement curve of pastefill block with reinforcement for 7 days curing time.

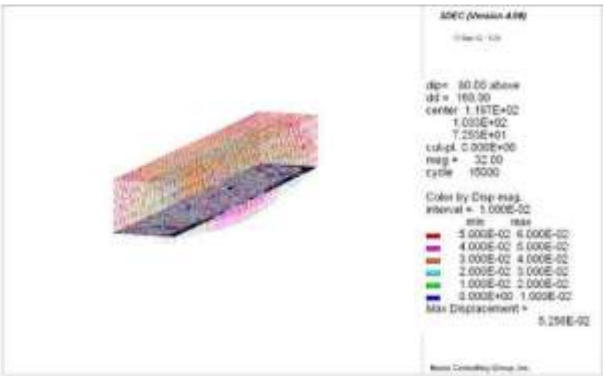

Figure 5.10. Failure type of pastefill block with reinforcement for 28 days curing time.

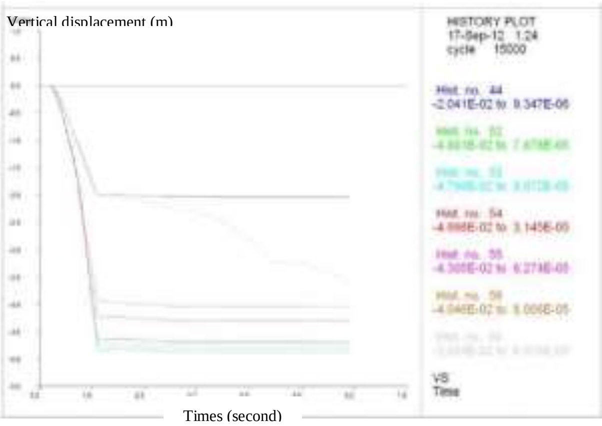

Figure 5.11. Y-displacement curve of pastefill block with reinforcement for 28 days curing time.

6. DISCUSSION

In Figure 5.1 and Figure 5.2 is the graph of the value of the safety factor of the width span under pastefill, where an increase in the value of FS from 7 days to 28 days, this is due to the drying time is still running until it reaches the standard time of 28 days, with increasing drying time to achieve the time standard is followed by an increase pastefill mechanical strength. While the design of width span is allowed to perform under pastefill mining with 14% cement content is 5 to 6 meters width span and should not be designed to span more than 6 meter high potential for failure occurs, the mining can be done at age 28 days or pastefill achieve strength standards, and should be reinforced with a stand-up bolt and chainlink mesh to prevent caving failure, flexural failure and even sliding failure on mass pastefill block.

From the modeling results, pastefill with 14% cement content with curing time of 7 and 28 days showed an unstable condition. But pastefill block with 7 days curing time will failure completely at the bottom of the block, not like a block pastefill with curing time of 28 days which just failure on certain parts at the base of the block. This is because the stength of pastefill with curing time 28 days stronger than pastefill with curing time 7 days in its ability to support himself. From the type or shape deformation seen, these two blocks will collapse by having failure on the bottom of the block. This type of failure in accordance with one of the predicted failure mechanisms from Mitchell 1991, is the caving failure. According to calculations by the equation 5.1a and 5.1b, failure of this type will occur in the 6 meter span width, and numerical modeling simulation or demonstrated at 6 meter span width occurs of the failure type is caving failure.

After reinforcement in the pastefill block, the numerical modeling results indicate that pastefill with curing time 7 days considered remains unstable although the installation of chainlink mesh given on the floor of the stope openings. Shown in Figure 4.8, the graph of y-displacement movements are still visible at the bottom of the pastefill block and will remain down as the addition of a cycle time. As for the pastefill block with curing time of 28 days, indicating that the maximum displacement blocks only reach about 5 centimeter in 15000 cycle (Figure 5.10 and 5.11.). So can be concluded that the pastefill block with curing time of 28 days was in stable condition with reinforcement and can be doing mining activities in under pastefill as shown in Figure 6.1. While pastefill with 28 days curing time is more stable and obtained UCS value 1.31 MPa, has full fill condition of 1.2 MPa.

Figure 6.1. Pastefill block with reinforcement that acts as a roof stope openings underneath.

7. CONCLUSIONS

The conclusion that can be taken in this study are :

1. Potential failure of pastefill at the location, according to the type of caving failure and flexural failure introduced by Mitchell 1991, on the width span of 6m under paste obtained FS < 2 for 7 days curing time and not yet stable and FS > 2 for 28 days curing time is stable.
2. Pastefill block with 14% cement content and curing time of 7 days and 28 days shows an unstable when not used of reinforcement, the failure type is caving failure occur in the numerical modeling.
3. In the numerical modeling, pastefill with a curing time of 28 days will be stable with the installation of chainlink mesh in the floor of the stope openings, while pastefill with curing time 7 days remains unstable.
4. Mining activities are permitted under pastefill block has reached the minimum curing time of 28 days.

8. ACKNOWLEDGEMENT

On this occasion, the author would like to thank for management and staff of the department of Kencana Underground Geotechnic of PT. Nusa Halmahera Minerals - Gosowong Halmahera Island, with the permission to conduct this research, and the management and staff of Tekmira Geomechanics Laboratory Center, Energy and Mineral Resources of Ministry of Indonesia Republic, which allowed us to do the laboratory test and permission to use 3DEC program for numerical modeling. The authors would also to thank the employees at Laboratory of Geomechanics Mining Engineering ITB.

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