Integration of mine planning to a constitutive model of a caving mine project under surface mining

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ABSTRACT

A major problem in mine planning is that first order analysis does not foresee the geomechanical consequences of the extraction of the material in a block or panel caving project. Particularly, the most important interactions between an open-pit and an underground mine in early stages of the transition are not well understood.

This paper presents the results and conclusions of a numerical modelling in MAP3D of three different production plans made with the mining planning tool, PCBC. This was applied in the first lift of a block caving project that is located below a mining surface with structural problems due to a big fault crossing the whole pit and near the new production level.

Finally, the study shows that the mining planning has a great impact on the distribution of the stresses in the rock mass, giving different results depending on the height of the columns for the transition of a stress caving to a subsidence caving. With this, the mining design and planning cannot be arbitrary, so it has to obey to a global engineering study and be supported by numerical models.

INTRODUCTION

A major problem in mining planning is that first order analysis does not foresee the geomechanical consequences of the extraction of the material in a block or panel caving project. Particularly, the most important interactions between an open pit and an underground mine in early stages of the transition are not well understood and what kind of influence exists with a particular production plan. Then without a geomechanical analysis, the final decision could bring unwanted results like considering the wrong dilution (and therefore ore), missing failures with high probability of occurrence and in the worst cases, loss of human lives when the open pit is still operating.

Parallel to the previous thing, it is not sufficient to know when the projects are going to interact. It is the obligation of the engineers to know which decisions affect the value of the business. In particularly, how the geomechanical consequences change depending on the different production plans. Then the aim of this investigation is to know these changes supported by numerical modelling, motivated because actually, the great part of this type of research maintain an unique production plan unknowing the importance of that.

Numerical modelling is an extended way to find adverse effects on transition mining. For this case there are two types of modelling to consider. One is called Boundary Element Method (BEM), this method uses limit conditions to compute, so the stress analysis is on the surfaces of the specified excavations. The other is the Finite Element Method (FEM) supported on equilibrium equations of control volumes. Consequently FEM analyses, in most cases, fit very well with reality and they require long periods of machine time. On the other hand, BEM analyses are faster and the results require calibrations according to the mining. For this research BEM analysis was applied like the choice for the model.

The next pages present the results of numerical modelling in MAP3D using BEM analysis of three production plans made with three different criteria for open draw points of PCBC [1]. This was applied in the first lift of a block caving project that is located below a mining surface with structural problems due to a big fault crossing the whole pit and near the new production level. This underground mine will start operating soon, extracting 60 [ktpd] by LHD system.

Before explaining the development of this problem it is important to summarise the operational constraints applicable to a mining project.

Draw rate: the draw rate will control the flow of rock at the draw point, defining its capacity, and needs to be fast enough to avoid compaction and slow enough to avoid air gaps. This parameter, between the opened production area, will give different configuration for planning and sequencing of a mine project.

Opened production area: at any given time within the production schedule it has to be constrained according to the size of the ore body, available infrastructure and equipment availability. Ultimately in a panel caving project, this is a large constraint and depending on it, the schedule could be concentrated in a group of draw points or not.

Rock mass strength [2]*:* defines the quantity of stress value the rock mass needs to fail. In mining this value determinates which kind of consequences exist in the rock mass due to a mine extraction. In this way, Hoek & Brown is the acceptable criterion used for this investigation.

Induced stress [2]*:* produced by the mining, the rock mass change their stress state. It means that there will be zones with different concentrated stress and as a consequence, sectors of more interest for geomechanical analysis. Thus it is possible to say that if the induced stress is greater than the rock mass strength, the rock has failed.

Period length constraint: the period length constraint gives the accuracy of a particular analysis and therefore it shows the interest in seeing the long term or short term view of the problem.

METHODOLOGY

A simple methodology was used and it is described below:

1. Study of background information available for the future transition mine. Specially to get the constitutive parameters to determinate the rock mass strength and the production rate for draw points.
2. Getting extraction mantles from the different criteria for opening points delivered by PCBC [1]. This aims to know which surface involves the cumulative extracted material every year, which is the period length selected for this analysis, for the different opened production areas.
3. Prepare graphic files to be used in MAP3D, simulating the different kind of rock bodies that will interact in the analysis. In this case: extraction mantles per year per production plan, the existed open pit and the fault.
4. Input the adequate in situ stress states in MAP3D for boundary conditions.
5. Determinate the progress of caveback along the time using the caving propagation factor (CPF) proposed by Flores in 2004 [3].
6. Conclusions.

PRODUCTION PLANS

To obtain the production plans, PCBC tools from Gemcom were used, scheduling a macro block extraction model. The model included the predefined sequence of extraction which will be used in this future mine. The sequence begins in the centre of the layout and advance to the sides like in *front caving*. Finally, PCBC was used to obtain the CAD surfaces of extraction mantles in the time. The next inputs were considered:

Economical parameters

To evaluate the appropriate value of the mining schedule, it was necessary to consider some economical parameters for the mine project which contemplate two minerals of interest, copper and molybdenum. The next table shows the global economical parameters.

Table 1 Economical parameter

	Cu	
Price	2	[US$/lb]
Mining Cost	7	[US$/Ton]
Recovery	88	[%]
Processing Cost	7	[US$/Ton]

Technical parameters

- Maximum production rate on regimen: 0,6 [tonnes/day/m^2]
- The extraction column was considered with a ratio of 12 [m]
- The best height of draw had a maximum possible of 400 [m] according to the literature [4]
- The layout used was Teniente type: 15 [m] x 17 [m]

- Mix model: Laubscher [1] with 160 [m] height of interaction zone and a dilution entry point of 50%
- Only one lift evaluated
- Production ratio: 60.000 [tpd]

Plans

Three balanced production plans were obtained by PCBC. These plans are called *Smooth*, *Combo* and *Auto* for save notation:

- Smooth Plan: the draw points are being closed progressively along the mine life and the new draw points as soon as possible
- Combo Plan: the draw points are closed as late as possible. This is a drastic schedule because the points are active until the last years of the mine maximising the production opened area, so it is possible to stick to the opening sequence.
- Auto Plan: the new draw points are opened as soon as possible and the maximum production rate per draw point is used

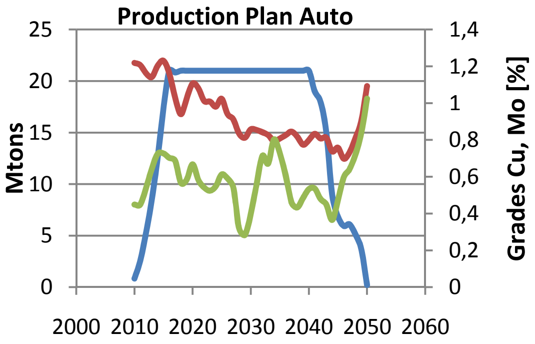

Figure 1 Production plan with Auto method

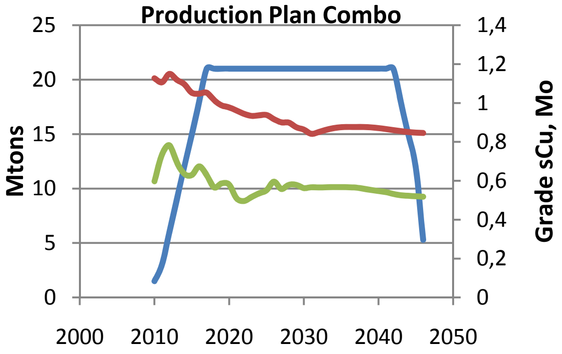

Figure 2 Production plan with Combo method

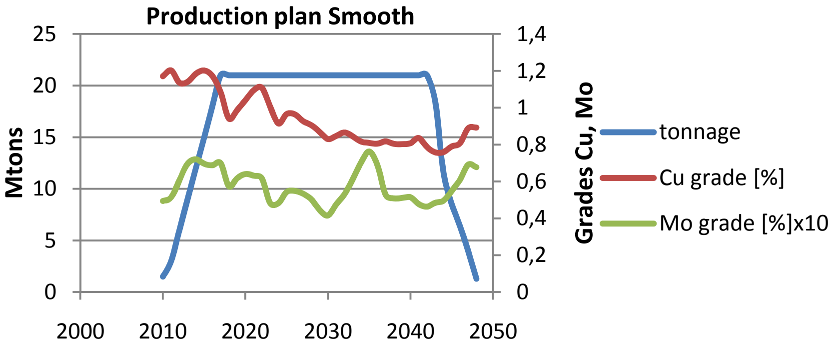

Figure 3 Production plan with Smooth method

It is possible to appreciate differences on grades between each production plan, because each method opens and closes the draw points in different ways. Combo has a decreasing grades profile, meanwhile the two other methods show grades profiles apparently without tendency. The changes are explained because the points do not open at the same time in each method, and also do not close at the same period.

BEM MODELLING

For the proposed evaluation in MAP3D it was necessary to draw 33 extraction mantles, where each mantle represent the extraction on a given year of one plan, based on the results from PCBC in the adequate format to eliminate boundary errors and minimise singularities. Therefore it was necessary to smooth the mantles of the first 11 years for each plan. And after that, the model of the fault and the final stage of the open pit were added to the software to see their influences.

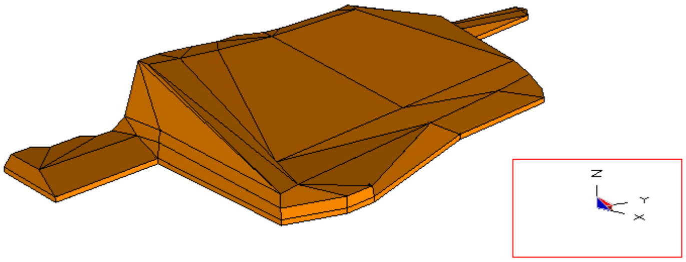

Figure 4 Extraction mantle drawn in MAP3D

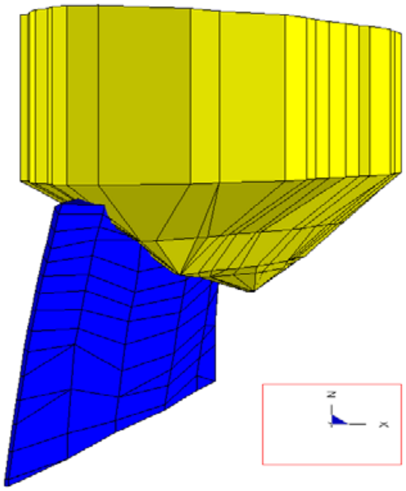

Figure 5 Final open pit and fault model

Materials properties and pre underground mining stress

Three types of materials were defined depending on which object they were applied to, all of them were in their elastic behaviour, even the fragmented as a good assumption.

Table 2 Materials

Materials	E [GPa]	ν
Host	22	0.24
Fault	0.9	0.29
Fragmented	1.03	0.29

The pre underground mining stress was necessary to define it for each object (extraction mantles, open pit, fault and host rock) independently like the boundary condition necessary for the BEM solve (All the values from Tables 2 and 3 were given by Delphos Mine Planning Laboratory Data Base). This way, the horizontal stress of the host material was considered constant in the space as the below table shows, but from the topography the vertical stress varies depending on the depth. Finally, the boundary condition for the fragmented rock was always surrounding the body considering particularly stress zero on the top of the extraction mantle, simulating the presence of the air gap. For software use purposes, the next table shows the pre underground mining stress considered in the model.

Table 3 Principal stress consideration

Host datum		**Fault datum**		**Fragmented datum**	
Depth	At the surface	Depth	At the surface on the open pit slope	Depth	At the top of the extraction mantle
S1 [Mpa]	0.0	S1 [Mpa]	0.0	S1 [Mpa]	0.0
S2 [Mpa]	0.0	S2 [Mpa]	0.0	S2 [Mpa]	0.0
S3 [Mpa]	0.0	S3 [Mpa]	0.0	S3 [Mpa]	0.0
Δs1 [Mpa/m]	0.0	Δs1 [Mpa/m]	-0.070	Δs1 [Mpa/m]	-0.002
Δs2 [Mpa/m]	0.0	Δs2 [Mpa/m]	-0.005	Δs2 [Mpa/m]	-0.006
Δs3 [Mpa/m]	-0.027	Δs3 [Mpa/m]	-0.005	Δs3 [Mpa/m]	-0.006

NUMERIC RESULTS

The numerical modelling was done on three computers with processor Intel Pentium Dual CPU E2180 2.00 GHz with 3.25 RAM. The computers took four hours to complete their calculus. Then, all the macro effects are summarised in the evaluation of caving propagation.

Evaluation of caving propagation

For the evaluation of how, when and where the caving propagation will be produced, the Caving Propagation Factor (CPF) was used, proposed by Flores and that has been used extensively since 2004 [3]. This expression relates the induced shear and the maximum shear that the host rock could have had before breaking. The CPF expression is:

$$CPF = \left(\frac{(S_1 - S_3)_{medido}}{(S_{1MAX} - S_3)_{HoekandBrown}} \right) = \left(\frac{(S_1 - S_3)_{medido}}{UCS * \left(\frac{S_3 * m_b}{UCS} + s \right)^a} \right) \tag{1}$$

Where *S1* is the major principal stress and *S3* is the minor principal stress. *UCS* is the unconfined compressive strength. Coefficients *s* and *a* are the Hoek & Brown parameters that depend on the material. Thus when the CPF is greater than 1 the rock has high probabilities to be broken. Nevertheless the parameters have some uncertainty so the criterion considered for rock failed was when CPF is greater than 1.5.

Graphic results of the CPF

The next tables and cross sections show the stress caving changing to subsidence caving, in other words, the interaction between the caveback and the surface in time obtaining with the CPF criterion which zone of the host rock has already broken.

Apart from the CPF, at the top of the images it is possible to see some local influences produced by the open pit, but those are effects of the modelling. Moreover, the CPF indicates only which rock failed but not the one with greater frequency of fractures. Then the analysis was focused on if the limit between the light blue with the dark green zones touches the mantle, because this represents the CPF equals to 1.5.

Auto plan

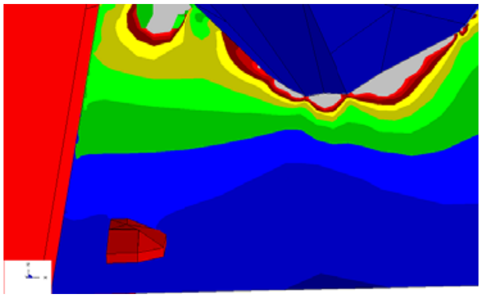

Figure 6 CPF evaluation for year 1 of operation for AUTO plan

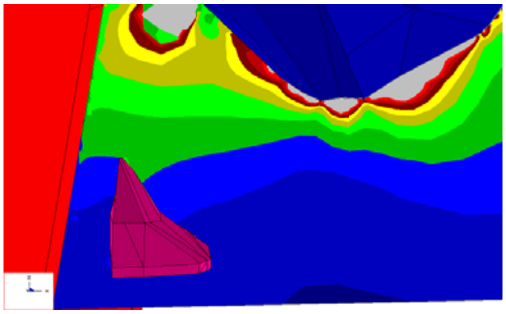

Figure 7 CPF evaluation for year 2 of operation for AUTO plan

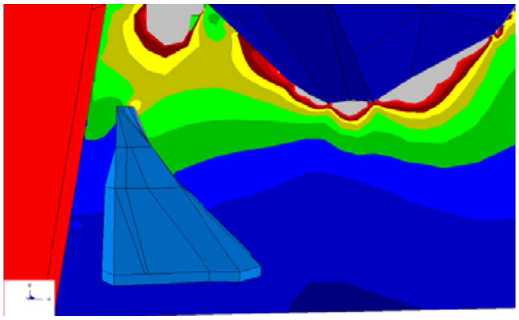

Figure 8 CPF evaluation for year 3 of operation for AUTO plan

Figure 9 Colour scale for the CPF

As can be seen, the connection happens in the second year of extraction and in the third year the subsidence caving is evident. When the mantle connects with the surface it has 80 [m] of height, concentrating the production at first draw points extracted.

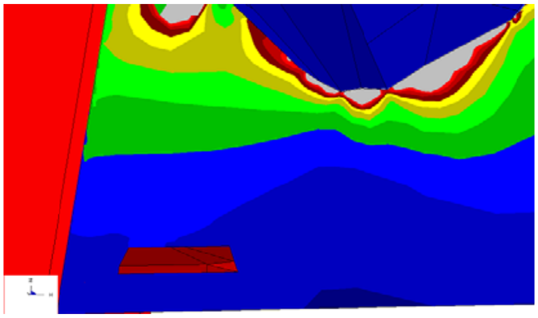

Figure 10 CPF evaluation for year 1 of operation for COMBO plan

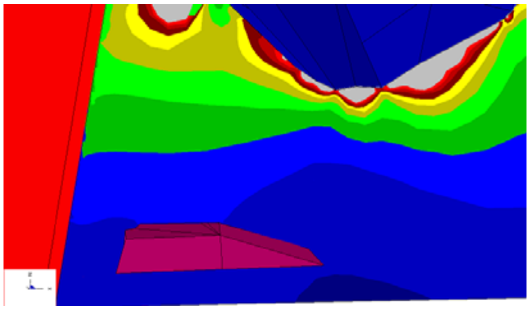

Figure 11 CPF evaluation for year 2 of operation for COMBO plan

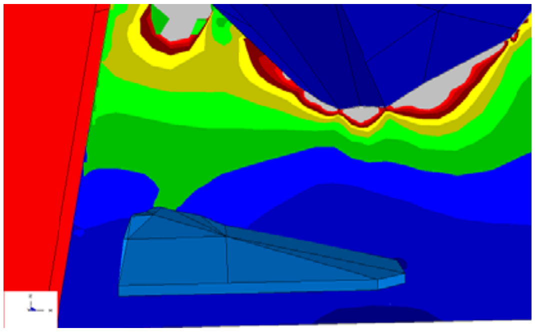

Figure 12 CPF evaluation for year 3 of operation for COMBO plan

Figure 13 Colour scale for the CPF

In this case the connection happens in the third year when the mantle only has 55 [m] of height. This difference was caused because the production was always concentrated in the new draw points and therefore with a big production area.

Smooth plan

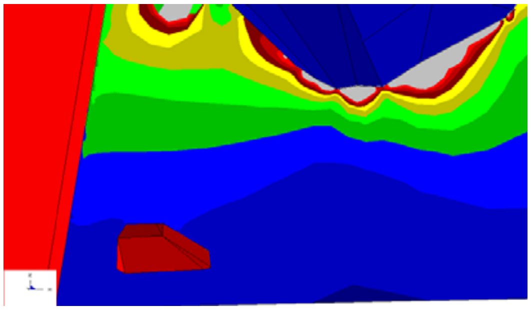

Figure 14 CPF evaluation for year 1 of operation for SMOOTH plan

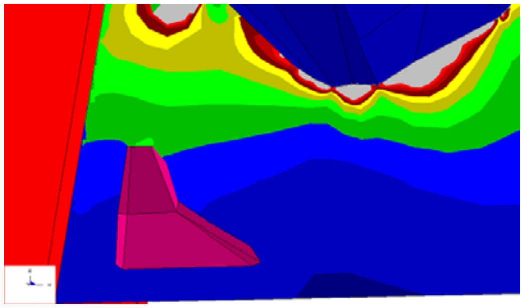

Figure 15 CPF evaluation for year 2 of operation for SMOOTH plan

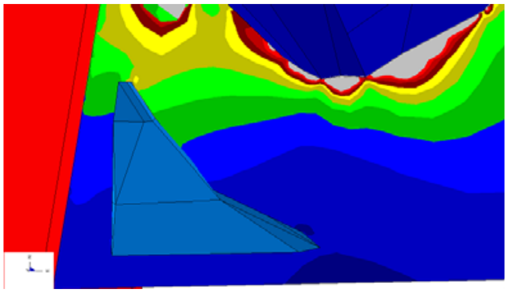

Figure 16 CPF evaluation for year 3 of operation for SMOOTH plan

Figure17 Colour scale for the CPF

Finally, the smooth case shows no big difference with the auto plan. The induced stress is relatively similar and the connection happens in the second year with 70 [m] of height.

CONCLUSIONS AND FUTURE WORK

In relation to the mine planning:

- Auto plan presents great variations of grades and rates of mining preparation.
- Combo plan needs to be reviewed because it is technically complicated to be fulfilled, because it proposes to have the entire footprint open all the life of the mine without considering the constructability.
- The smooth plan absorbs the problems founded in the other methods, but has the inconvenient that it is better for panel caving and not for macro blocks, which is not the case for the present hypothesis.

In relation to the geomechanicals repercussions:

- Analysing only the numerical results, all methods have some interaction with the fault since the beginning of the operation, with no detailed analysed consequences, nevertheless the first years appear to be lower enough to be depreciated according to the graphs.
- For the three numerical modelling, there is a connection with the surface in the first years. In the second year in the case of auto and smooth plan and the third year in the case of combo plan. Additionally, it is highly probable that this subsidence caving starts at the bottom of the pit, so the possibility of a sliding failure increases. But the caveback does not have a direct contact with the surface and then it is a combination of the caving propagation and open pit effects.
- The mine planning induces strongly in the geomechanical effects. Moreover it is possible to see that between analysed plans there is a difference of height of column of more than 25% when the caving connection is produced.

Integrating planning and geomechanical:

- The planning of caving an underground mine must consider a global stability study. If such studies are not carried out, it could compromise the feasibility of the whole project, affecting the mineral resources, recovery and the way to extract the mineral.
- In a technical evaluation, the Smooth plan presents the best conditions to develop the project, but it has to be mixed with Combo plan to be reliable. It is appropriate to schedule in time intervals to give the best alternative per periods and then choose the best option. In that way, considering that when the caving connection is produced it is possible to draw with the maximum production rate, the entire schedule after that has to be reconsidered.

Future work:

- For academic purposes and to compare the results and methodology of this paper, it is recommendable to do the same analysis using FEM to have robust outcomes.

ACKNOWLEDGEMENTS

The authors would like to thank Delphos Mine Planning Laboratory for providing the tools and financial support to make this research possible.

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