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Influence of pit wall stability on underground planning and design when transitioning from open pit to sublevel caving

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1 INTRODUCTION

For orebodies that extend beyond the economic depth of an open pit, there is an opportunity to go underground to further exploit the reserve provided the economics allow. Mining engineers prepare and plan for the new challenge of transitioning from open pit to underground operations. The planning and design of the underground mine has to be within the confines of safety and economics so as to profitably extract the ore. Furthermore, detailed attention must be given to the stability of the pit wall and how it will influence the position of the portal and subsequent excavations, that is, primary and secondary developments that will enable access to the orebody, as well as service infrastructure.

The positioning of underground infrastructure when transitioning from open pit to underground operations is a difficult exercise which involves balancing of geotechnical aspects with mine planning and design, all feeding into the economics of the project. Poor planning and inadequate consideration of geotechnical properties can have devastating consequences such as uncontrolled backbreak, failure of pit walls, loss of lives, loss of equipment, excessive dilution and even loss of the mine. This paper will investigate the influence of pit wall stability on underground planning during transition from open pit to sublevel caving operation. The paper will further seek to derive a numerical analysis aided design for the positioning of underground infrastructure outside the zone of pit wall instability and geotechnical influence, which is a study area on the boundary of two disciplines, namely rock engineering and mine planning. A case study of Mine A located in Africa was used for the research. Mine A consists of a dual kimberlite deposit spaced at 800m apart and the economic limit of the pits were reached at 300m from surface.

2 DESIGN AND ANALYSIS

For Mine A, the main geotechnical risks that faced the project were pit slope stability, ramp stability for the access of underground workings and also underground backbreak. These risks had the potential of causing failure for the in pit accesses. Hence numerical modelling was used to determine position of infrastructure outside the zone of influence. The main slope stability risk for the open pit operations for the case study was small scale wedge and planar failure at a bench scale; with stack and overall slope stability influenced by individual continuous geological structures that could result in stack scale wedge formation. The presence of an elevated water table had a significant negative impact on the overall slope stability and a well maintained dewatering program required for on-going stability of the slopes. The conceptual set-up of Mine A is shown in Figure 1.

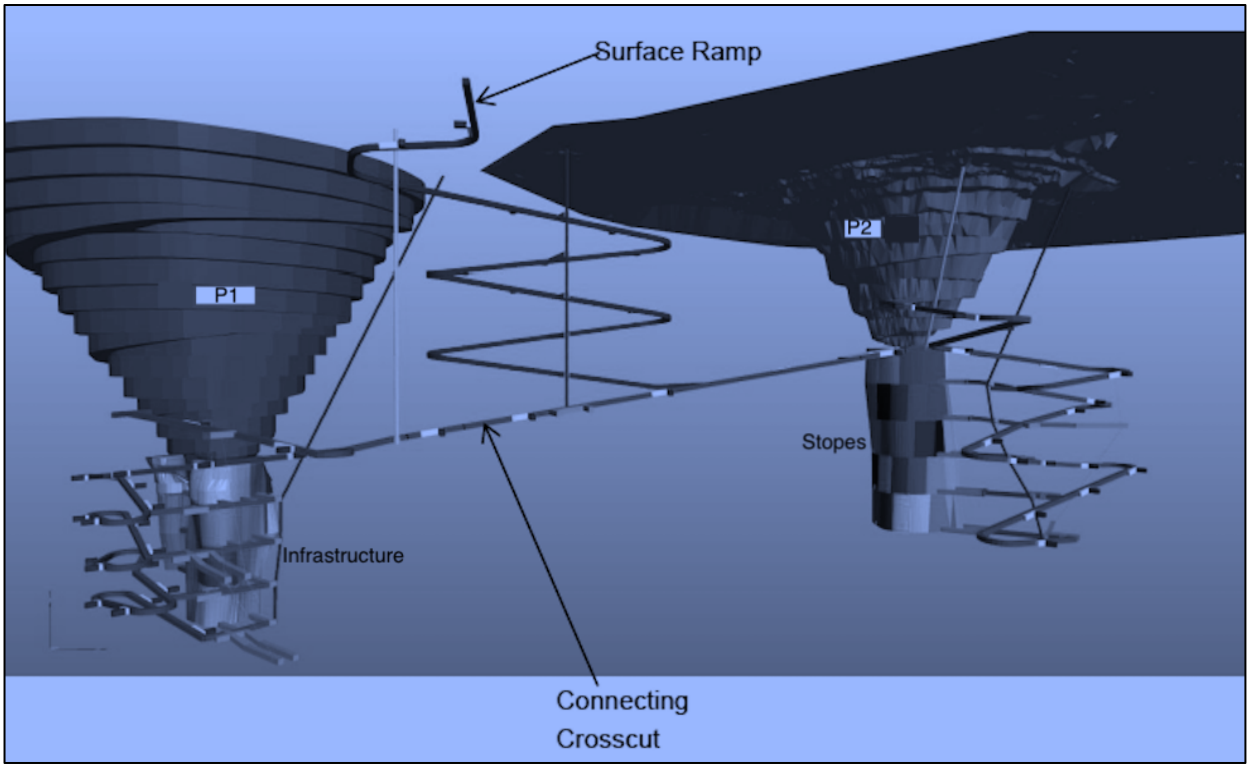

Figure 1. Set-up of Mine A.

For Mine A, siting of major underground infrastructure was done based on the geotechnical information which indicated green zones with minimum failure risks. Underground infrastructure that was considered for Mine A projects include siting and placement of:

- Ramp development
- Connecting drive for the two underground workings
- Ventilation shafts
- Underground workshop
- Drilling water reticulation
- Dewatering system
- Electrical system
- Secondary escape route
- Level drives

In line with the aim of the paper, the researcher sought to investigate the effect of stress changes around the pit wall with progression of mining using numerical analysis with *FLAC3D* (Itasca 2016). From this exercise, mine planning and design could be done with confidence in terms of siting of underground infrastructure such as declines, ventilation shafts, underground stations, pump chambers and primary development meant for life of mine. Parameters that were considered for the numerical model include geomechanical properties, initial conditions, boundary conditions, groundwater and consideration of the mining sequence. A numerical analysis was done for open pit to underground transition for both P1 and P2 of Mine A, taking note of pit slope stability, interaction of pit and underground with progression of mining and siting of underground infrastructure.

The plan for Mine A was to deplete the kimberlite pipes by top down sub level caving through 40m slices, 4 slices for Pipe A and 5 slices for Pipe B. This also involved developing the ramps and drives as close as possible to the orebody, to cut on the development costs and time. Stability analysis of the pit walls and the zone of geotechnical influence with progression of mining was done for both Pipe 1 and Pipe 2 using an elastic analysis based on the geomechanical parameters of the mine. The *FLAC3D* (Elastic, transversely isotropic model) analysis using geotechnical parameters in Table 1 provided safety factor iso-shells for each pipe.

Table 1. Mine A geotechnical design parameters.

Rock type	UCS	RMR	GSI	mi	c (kPa)	Φ (°)	E (GPa)
Breccia	72	45	40	6	262	34	1.9
Granite	133	63	57	16	1004	55	9.5
Kimberlite dyke	120	61	56	6	977	44	4.9
Kimberlite pipe	65	61	56	6	694	40	3
Leached granite	25	48	43	6	184	27	0.5

3 RESULTS AND DISCUSSION

As the underground mining progress from stope 1 to stope 5, there is confinement that is lost on the walls of the mined-out area. This will progressively cause rockfalls into the excavation. The final backbreak profiles for the pits give an indication of the extent of the zone of influence at depth. Based on experience and an analysis of similar cases, a Factor of Safety of 2 was chosen and validated with numerical modelling. This shell excluded underground infrastructure within its iso-shell. Therefore, the extent of the backbreak and zone of influence at depth was used as a guide to modify and re-position the underground infrastructure. Life of Mine infrastructure has been positioned outside of the backbreak and critical infrastructure such as workshops, ventilation shafts, crushers, spiral declines and underground pump chambers has been positioned outside of the zone of influence. The modelled factor of safety shells are illustrated in Figure 2.

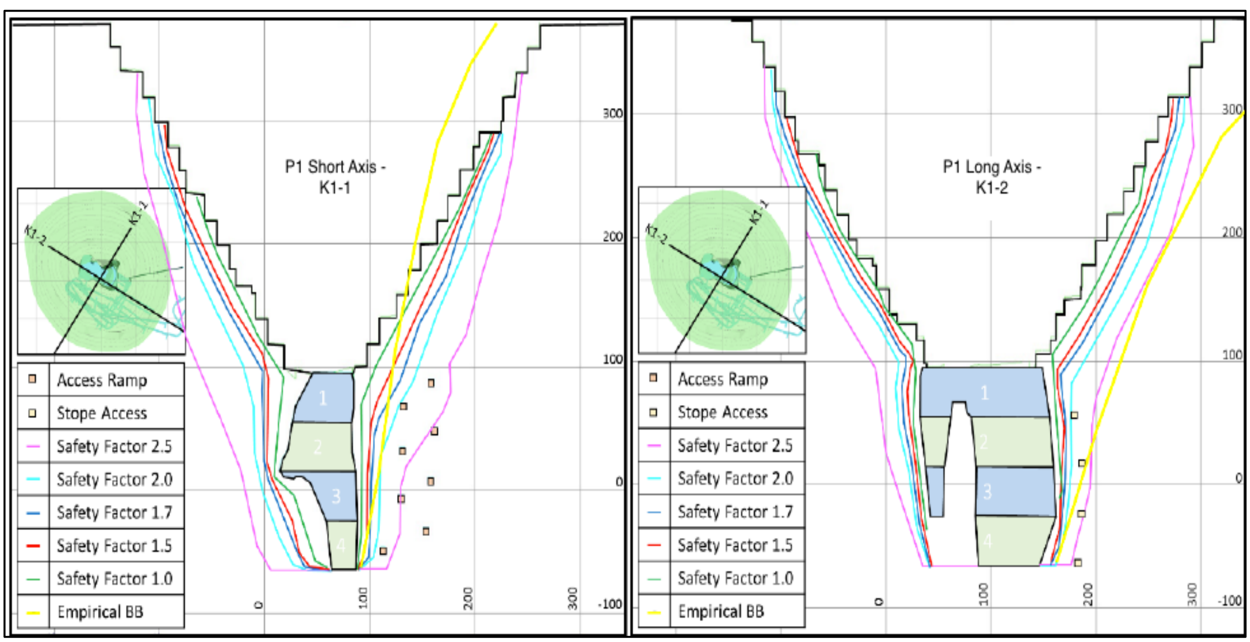

Figure 2. Modelled Factor of Safety shells.

4 CONCLUSIONS

The evaluation of pit wall stability when transitioning from open pit to underground is a key planning, cost and safety consideration of an operation. In terms of Mine A, the proposed underground infrastructure were long term excavations which were required to be stable during the life of mine. The positioning and siting of underground infrastructure outside the zone of geotechnical influence caused by stress changes and loss of confinement as mining progressed from pit bottom to the lower levels was determined. Modelling was done in *FLAC3D* which incorporated the sequence of mining from the top stope to the last stope for Pit 1 and Pit 2. This was done for various Factor of Safety ranging from 1 to 3. Though the Factor of Safety of 1.6 is acceptable in industry for underground mine excavations, the author chose a Factor of Safety of 2, which is conservative making sure all critical excavations would be outside the backbreak zone. A Factor of Safety of 2 also catered for the unknowns of rock mass behavior.

REFERENCES

Itasca Consulting Group, Inc. 2016. *FLAC3D – Fast Lagrangian Analysis of Continua in 3 Dimensions, Ver. 6.0 User's Manual*. Itasca: Minneapolis.