Determination Of Optimal Stope Strike Length On Steep Orebodies Through Laser Scanning At Lubambe Copper Zambia

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Abstract: Lubambe Copper Mine is located in Chililabombwe, Zambia, and is a joint copper mining venture with three partners that include African Rainbow Minerals (40%), Vale (40%) and the Government of Zambia (20%). The current mining method utilises Longitudinal Room and Pillar Mining (LRP) on 70m long panels strike length. However, these long panels have resulted in unprecedented levels of dilution mainly from the collapse of hanging wall laminated ore shale (OS2) leading to reduced recoveries. Observations made underground show high variability in geological and geotechnical conditions of the rock mass with factors such as weathering on joints, lamina spaced joints and stress changes induced by mining all contributing to weakening and early collapse of the hanging wall. Therefore a study was undertaken to establish the optimal stope strike length of steep ore bodies at Lubambe. The exercise involved the use of Faro Laser Scanner every four stope rings blasted, with time when the scan was performed noted. The spatial coherence of lasers makes them ideal measuring tools in situations where measurements need to be taken in inaccessible areas. Recent advances in laser scanning coupled with the exponential increase in processing power have greatly improved the methods used to estimate stope tonnages extracted from massive inaccessible stopes. The collected data was then used to construct digital three dimensional models of the stope contents. Sections were cut every metre with deformations taken and analysed with respect to time. Deformation rates from the hanging wall was reducing from 0.14t/hr to 0.07t/hr between rings 1 to 8. This reduction was as a result of slot blasting that involved drilling and blasting a number of holes at the same time. Between rings 8 to 25 deformation was constant averaging 0.28t/hr and between rings 25 and 28, a sharp increase in deformation rate was experienced from as low as 0.16t/hr to 6.33t/hr. This sharp increase defines the optimal stope length as 50 m beyond which there is excessive levels of dilution mainly from the hanging wall.

Keywords: Geotechnical investigation; Optimal Stope length; Steep Orebody; rock mass; time dependent deformation

Introduction
A geotechnical study was undertaken at Lubambe Copper Mine to evaluate the optimum stope strike length on its steep orebodies (>55°). Lubambe is located in Chililabombwe, Zambia, Figure 1, and is a joint copper mining venture with three partners that include African Rainbow Minerals (40%), Vale (40%) and the Government of Zambia (20%).

The current mining method utilises Longitudinal Room and Pillar Mining (LRP) on 70 m long panels strike length as shown in Figure 2. However, these long panels have resulted into unprecedented levels of dilution mainly from the collapse of laminated ore shale (OS2) forming the hanging wall leading to reduced recoveries. Understanding the mechanisms of time dependent behavior of hard rocks is cardinal when deciding on the optimum stope strike length (Drescher, 2002). The current extraction ratios achieved using LRP are around 54%, far short of the planned 75%. At the mine, there is an emphasis to control stope spans, drilling and blasting operations to limit dilution. Stope design was based on the combination of Hydraulic Radius (HR) which defines the Stope geometry together with a Matthews stability Number (N’) which defines the rock mass conditions.

Figure 1: Location of Lubambe Copper Mine

Figure 2: Longitudinal Room and Pillar Mining Layout
Observations made underground show high variability in geological and geotechnical conditions of the rockmass with factors such as weathering on joints, lamina spaced joints and stress changes induced by mining all contributing to weakening and early collapse of the hanging wall. It was also evident that damages on the hanging wall was as a result of excessive charging (0.54kg/t) compared to the recommended 0.23kg/t and over drill towards the hanging wall due to limited controls put in place. Some preliminary investigations on the optimum strike length conducted by SRK consultants (2014) and numerically modelled in MAP3D reviewed the following:

- Optimum length of approximately 22 m equivalent to 11 rings per panel.
- Staggered pillars providing less tensile zones as compared to the aligned (chain) pillars.

However, history shows that stope lengths as long as 70 m on strike were mined on steep orebodies i.e > 55° (SRK, 2009). The geotechnical design review conducted by consultants (SRK, 2014) recommended a strike stope length of 22 m. This entails development of slot raises every 22 m which impacts productivity and increases cost on explosives and drilling consumables. From the production point of view, slot developments every 22m was not feasible. Hence, the need to review ground movements in stopes by using laser technology, as discussed in this paper.

Main Objective
To investigate the optimal stope strike length of steep orebodies at Lubambe Copper Mine.

Sub-Objectives
- To investigate time-dependent failure on the hanging wall as stoping progresses.
- To establish the critical value of hanging wall volumetric deformation as stoping progresses.

For convenience in this paper, volumetric deformation has been expressed in tonnes per hour (t/hr).

Methodology
The study conducted involved five stages;

1. **Stope Identification:**
An area to conduct the trial was identified on Ramp 4-251S panel 3. The area was selected as it met the requirement of the orebody dip at 55°.

2. **Ring design and drilling:**
Production rings were designed with a burden spacing of 2 m. The designed stope long blasthole rings were marked underground by the Survey Department in readiness for drilling. A total of 32 rings were marked for drilling translating into 64 m panel strike length. Drilling of the production holes was conducted using a CMac machine. The rig utilises lasers on the side walls that minimises errors when drilling. All the 32 rings were drilled as per design layout provided. This is as shown in Figure 3.

Figure 3: Ramp 4-251S Isometric view of Panel 3 Ring design and drilling

3. **Hole Survey and Ring Blasting**
A hole survey using a down hole survey camera was performed on all the drilled holes. The purpose of the hole survey was to check and confirm the quality of drilling works conducted before blasting as shown in Figure 4. Usually hole deviation is a common problem associated with production drilling and will impact on the blast outcome. Charging and blasting of the stope was conducted under close supervision by the Geotechnical personnel to ensure quality works. Only one ring was blasted and mucked at a time. This was done in order to minimise shock waves on the surrounding rock mass.

Figure 4: plan (left) and section (right) of Hole Survey onR4-251S panel 3

4. **Faro Laser Magnetic Scanner**
A Faro laser magnetic scanner was utilised to collect dense data set that was used to create a point cloud of geometric samples inside the inaccessible stope as shown in Figure 5. Various applications for laser scanners have emerged over years since the functional laser scanner was developed around 1960. The special coherence of lasers make them ideal measuring tools in situations were measurements need to be taken in inaccessible areas. This property give raise to Cavity Monitoring System (CMS) and Laser scanners. The technology enables huge volumes of spartial data to be collected within a short period of time that is used to construct a digital, three dimensional model of various stope constituents such as total volume extracted, Ore volume extracted, footwall and Hanging wall dilutions. (Faro lasser focus, 3D Technical Manual, October 2011).
3D laser scanner produces dense point clouds containing millions of points that provide incredibly 3D detailed images of large scale geometries. Multiple scans from different positions can then be compiled to create a cohesive point cloud. During Stope scanning at Lubambe, the scanner is mounted on a dolly which in turn is mounted on a horizontal open lattice truss attached to a monocycle. This contraption is pushed into the stope and the rear end is stabilised by a heavy duty survey tripod. This enables approximate levelling of the scanner. The scanner has a tilt correction capability that will compensate for vertical axis errors of up to 5°. The scanner is reeled into the stope by a rope and pulley and is activated by remote control (Any Android™ tablet with Wi-Fi and flash player works for this). The surveyor coordinates a mini-prism by total station and swaps this with a registration sphere. The coordinates are then used to geo-reference the scan which would have otherwise been in a localised coordinate system with the scanner location defining the origin. The laser scanner also provides the option of setting the desired scan resolution and measurement quality at this stage. The scan resolution on the scanner is defined as the distance between two successive measurements 10m away from the scanners position. The point data collected by the scanner (Figure 6), is of such high resolution that even at the lowest settings, the direct conversion of the scan data to .dxf or .dwg formats makes the resultant file too large to handle in a manner that is technically efficient. Once the geo-referencing process is complete in the generic software, xyz coordinate list of points 0.2m apart is generated. This equates to discarding well over 80% of the measured data, as scan points are measured as densely as 1mm apart in areas close to the scanner. The scan data is run through software called a scan filter which is capable of reading the output from the scanner and generating the coordinate list.

**Figure 5: Fero Laser Magnetic Scanner**

In generic laser scan usage in tunneling and mining purposes, the typical application is the point by point comparison that enables engineers to identify areas that might either be too tight or may require back fill. The Lubambe survey team took this aspect of the scan analysis and defined the various parameters of the stopes that were non-compliant to the design and derived a series of wireframe models as shown in Figure 7.

**Figure 7: Stope dataset**

During this exercise scanning was conducted every four rings blasted in order to pick as much deformation experienced as possible. The scanning time was recorded. It was noticed that scans were overlapping from the previous scans. Ideally the point clouds could overlap over a stretch of approximately 16m inside the inaccessible stope. This was observable from the differently coloured sectional point clouds. Sections were then cut every 1.0m with deformation changes analysed and recorded.

**Findings and Discussion**

The exercise conducted revealed that significant levels of dilution were emanating from the hanging wall rather than from the footwall. The levels of deformation were noticed to be increasing as stoping progressed which is mainly due to influence of hydraulic radius (HR) which defined as ratio of surface area of the stope back and its surface perimeter and Matthews stability index “N” defined as

\[
N = Q' \times A \times B \times C.
\]

Where;

- **N** - Matthews Stability Number,
- **A** - Rock Stress Factor
- **B** - Joint Orientation Adjustment Factor
- **C** - Gravity Factor.

From ring 1-8, deformation from the hanging wall was noticed to be reducing from 0.14 t/hr to 0.07 t/hr. This is because of the effects on slot blasting that usually involves drilling and charging a number of holes. The amount of explosives used transmit a lot of shock waves to the surrounding rock mass. However, from rings 8-25 it was realised that the deformation rate became constant averaging 0.28 t/hr. At this stage the stope maintains its stability and also blasting of these rings does not transmit excessive shock waves since blast throw occurs in the already open free face. From rings 26 and 27, a sharp increase in the deformation rate was experienced from as low as 0.16 t/hr to 6.33 t/hr. This sharp increase identifies the critical length beyond which there is excessive levels of...
dilution leading to uneconomical mining. At this length, it was deduced that there is sudden change in stress regime, mainly due to effects of Hydraulic Radius and Matthew stability number. From rings 27-33, the rate of deformation increased sharply to about 8.39 t/hr. Therefore according to the investigations and analysis conducted, the optimal stope length on steep orebodies at Lubambe should be 50m long (25 rings). Exceeding 50 m results into excessive dilution from the hanging wall as shown in Figure 8.

![Figure 8: Graphical presentation of optimal stope strike length of steep orebodies at Lubambe Copper Mine. (Optimal at end of ring no. 25.)](image)

Hole survey conducted revealed that some production holes drilled were off design. Some holes were drilled longer than design and others shorter than the design as shown in Figure 9. If this is not checked out during charging and blasting, it results into formation of creeps and over breaks. In areas where this was noticed charging and blasting was under close supervision

![Figure 9: Plan (left) and Section (right) Hole Survey of drilled holes on R4-251S.](image)

**Conclusion**

The main objective was to investigate the optimal strike stope length of steep orebodies (greater than 55 degrees) at Lubambe Copper Mine. The main objective of optimal stope length was achieved resulting in the recommendations and implementations of satisfactory stopes with minimal dilution and Stope collapse due to self-mining.

- To investigate time-dependent failure on the hanging wall as stoping progresses; From ring 1-8, deformation from the hanging wall was noticed to be reducing from 0.14t/hr to 0.07t/hr. This is because of the effects on slot blasting that usually involves drilling and charging a number of holes. From rings 8-25 it was realised that the deformation rate became constant averaging 0.28t/hr. It is believed that at this stage the stope maintains its stability and also blasting of these rings do not transmit excessive shock waves since blast throw occurs in the already open free face. From rings 26 and 27, a sharp increase in the deformation rate was experienced from as low as 0.16t/hr to 6.33t/hr. This sharp increase identifies the critical length beyond which there is excessive levels of dilution leading to uneconomical mining. At this length it is believed that there is sudden change in stress regime due to effects of Hydraulic Radius and Matthew stability number. From rings 27-33, the rate of deformation increased sharply to about 8.39t/hr.

- The optimal stope strike length on steep orebodies was established as 50 m. A sharp increase in the deformation rates from as low as 0.16 t/hr to 6.33 t/hr identifies the critical length beyond which there is excessive levels of dilution resulting in uneconomical mining.

**Recommendations**

From the laser scanning, it was recommended that stope strike length be set at 50 m thereafter. Subsequent stopes mined at 50 m have proved stable with realistic dilution levels. Laser scanning in the stopes was found to be very useful in fine tuning numerical modeling.

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**References**


