With the removal of the majority of the shallow mineral reserves there has been an increase in the mining depths in the South African mining industry. This has, in turn, changed the industry’s and stakeholders’ perceptions of risk associated with mining-induced instability. In recent years the increased mining depth, particularly in open pits, has led to an increase in pit slope failures, which has highlighted the need for appropriate and effective pit slope management programmes. Such a programme comprises many facets, including mine hazard plans, regular slope inspections, cleaning of interim and final pit faces, blasting practices, histories of failures, pit depressurization, stormwater control and evacuation procedures. However, it is arguably in the field of slope monitoring that the most significant strides have been made in terms of new technologies and best practice in open pit mining geotechnics, with the introduction of technologies such as laser scanners and slope stability radar. This paper seeks to illustrate the operational benefits associated with the implementation of new technologies into open pit mining, using AngloGold Ashanti’s Geita Gold Mine in Tanzania as an example.

Introduction

On 3 February 2007 the south western slope of Cut 4, Nyankanga Pit, Geita Gold Mine, collapsed resulting in a failure approximately 200 m high and 270 m wide, which equated to approximately 7.3 million tonnes of material reporting to the pit floor.

Failure is thought to have been initiated following blasting at the toe of the slope, which resulted in an initial acceleration in slope movement, followed by a four-week regression phase. Heavy rainfall thereafter, however, remobilized the slope, resulting in ultimate failure. The total time from initial movement to slope failure was twenty days. The cause of the failure was subsequently identified to be due to a known shallow-dipping, north-orientated surface in the pit wall and a previously unidentified release surface that formed a large meta-stable wedge structure (Painter, 2007), which failed during subsequent mining of the western wall. The two main structures identified are illustrated in Figures 1 and 2 showing Cut 4 pre- and post-failure respectively.

Management of the 2007 failure

Despite the magnitude and swiftness of the Cut 4 failure, the Nyankanga Pit was safely and effectively evacuated with no resulting injuries to personnel, or damage to equipment. This feat was achieved primarily due to the fact that Geita Gold Mine had deployed slope stability radar in the Nyankanga Pit, as part of the risk management strategy, due to stability-related concerns associated with the south western wall of the pit, which had been identified in March 2006.

As the primary risk management tool, the radar unit initially detected movement of the slope on 15 January 2007. Thereafter, a period of three days followed in which the movement rates began to regress before settling into a steady state for a further twelve days. Five days prior to the
failure, the movement rates began to accelerate. All in all, a period of some twenty days elapsed prior to failure on 3 February 2007. Deployment of the radar unit allowed the constant monitoring of the movement rates and facilitated informed decision making in terms of the continuation of mining operations and the safe and timely withdrawal of personnel and machinery on 3 February 2007 at 10:00, some 3.5 hours prior to the failure. The timeline leading up to the Nyankanga Pit failure is depicted in Figure 3.

New technologies in geotechnics

The failure in the Nyankanga Pit at Geita Gold Mine had the effect of illustrating the importance of having an appropriate risk management procedure in place that incorporated best practice through the use of new technologies in order to counter the different levels of geotechnical hazards and subsequent risk.

Safe mining operations are, to a large extent, reliant on the development and implementation of appropriate slope management programmes. Within any suite of slope management protocols, arguably the most important component relates to slope monitoring, as it is slope monitoring that typically comprises the primary risk management tool in the majority of surface mining operations. Great strides have been made in the development of automated and real-time monitoring systems that can be utilized in surface mining operations.

Although by no means ‘new’ technologies in the strict sense of the word, there are three slope monitoring systems that are generally regarded as constituting the state-of-the art in terms of surface mining applications, namely:

- GeoMos’ prism monitoring
- Riegl laser scanning
- Slope stability radar.

Towards an integrated slope management system at Geita Gold Mine

The three slope monitoring systems are not interdependent, but are rather used in conjunction with one another to monitor different aspects of geotechnical risk to form an integrated risk monitoring system.

Application of the ‘GeoMos’ prism monitoring system

‘GeoMos’ is a continuous prism monitoring system comprising an integrated monitor and analyser function. Hardware requirements for the system comprise the Leica TCA 2003, which has an angular measurement accuracy of 0.5” and a linear measurement accuracy of 1mm+1ppm. Data assimilation is automated. Analysis output allows the direction and velocity of a moving prism to be derived.
The Leica GeoMos system was commissioned at Geita Gold Mine in July 2007. A schematic diagram illustrating the GeoMos system deployed at Geita Mine is depicted in Figure 4. Screen grabs illustrating the monitor and analysing functions of the system are depicted in Figures 5 and 6 respectively.

At Geita Mine, the ‘GeoMos’ system is deployed to monitor the active mining areas within the greater Nyankanga Pit; a total of fifty-six prisms being automatically monitored. In addition to the fixed, automated data collection in Nyankanga Pit, use is also made of a second, mobile, ‘GeoMos’ system to monitor slope movements in areas not in the line-of-sight of the fixed unit, as well as movements in Lone Cone Pit, at the ROM pad and tailings dam respectively.

The second, roving ‘GeoMos’ system is fully automated with data being transferred directly to a mobile laptop PC, which is subsequently downloaded to the ‘GeoMos’ PC through the Geita Gold Mine network upon completion of the data assimilation. The roving ‘GeoMos’ system is illustrated in Figure 7.

**Application of the Reigl laser scanner**

The laser scanner system makes use of state-of-the-art laser measurements to facilitate the monitoring of open pit slopes. The system comprises a number of modules, namely:
- Site monitor—control
- Site monitor—scheduler
- Site monitor—analysis
- Site monitor—volumes

Of these, the control and analysis modules are of primary interest for the purpose of this paper.

Effectively, the system is utilized to monitor a pre-defined grid at a selected time interval, the results subsequently being displayed and the time series monitoring data analysed.

![Figure 4. Schematic diagram of the Geita Mine GeoMos prism monitoring system](image)

![Figure 5. Photograph of pit slope monitored by GeoMos system](image)
The key features of the system include, inter alia (Reutech, 2009):

- The remote monitoring of XYZ coordinates
- High precision repeatability
- Automated operation for continuous monitoring
- Alarm module
- Ease of deployment and maintenance
- Geo-referenced photos.

The Riegl LPM-2K scanner unit is capable of measurements up to a range of 2 500 m and has an accuracy of between 25 mm–50 mm while measuring four points per second. Simply, the prisms are scanned and the centre point of each calculated, which facilitates:

- The generation of a range correction factor which compensates for changes in both the air temperature and the atmospheric pressure
- The generation of a transformation matrix to ensure that the scan data is allocated to the correct project coordinate system
- A check to ensure the system is measuring correctly.
- A check to ensure that there has been no movement of either the scanner or the reflectors.

Thereafter, the area and point data are compared using SiteMonitor, the alarm modules are set and the results displayed (see Figure 8). A schematic diagram illustrating the principle of the system is presented as Figure 9.

The Riegl laser scanner, which was commissioned at Geita Gold Mine in August 2007, was procured specifically to monitor the failed footwall material during the mining of the Cut 6 push back. This was due to the fact that the initial prism monitoring points had been destroyed as a consequence of the failure and there was no access to the pit slope to facilitate their replacement. Consequently, the Riegl laser scanner was seen as the optimal platform to carry out continuous monitoring of the failed material for the duration of the Cut 6 mining behind the failure, a period of 1.5 years, being a cheaper option than radar. A rear view of the laser scanner at Geita Gold Mine is presented as Figure 10.

The laser scanner and ‘GeoMos’ monitoring network at Nyankanga Pit, Geita Gold Mine is illustrated in Figure 11. Typical output from the laser scanner, showing a small area of movement detected, is presented as Figure 12.

**Application of the slope stability radar**

Currently, radar monitoring systems may arguably be regarded as constituting the state-of-the-art ground control management system that can be deployed in open pits with respect to the monitoring of pit wall stability. The radar units are designed to provide real-time, all weather, day and night surveying and slope measurement capability in a harsh mining environment. Currently, AngloGold Ashanti Limited deploys two of the four systems available on its operations, namely:
The Australian-developed GroundProbe SSR-X system, or The South African-developed Reutech MSR system. Examples of the two radar units are illustrated in Figures 13 and 14 respectively.

The key features of these systems include, inter alia:

- An operating range typically between 50 m and 2 700 m, depending on which system is used
- Full remote operation
- Selectable scan speeds (1 m–30 m)
- High speed wireless communication
- Integrated weather station to alleviate the effect of atmospheric variations
- Operation between -10°C and 55 °C
- Scans 270° horizontally and 120° vertically (see Figure 15).
- Operation in extreme dust
- Operation in wind less than 60 km/h (GroundProbe max. operational wind gust speed of 88 km/h)
- Operation in rain less than 60 mm/h
- Detection of slope movements greater than 0.1 mm–0.2 mm, depending on which system is used
- Unit is self powered.

Typically, these units are deployed in geotechnically high risk areas where there is a low level of confidence in the ability of prisms and visual inspections to predict an impending failure timely to allow for the safe evacuation of personnel and equipment from the mining environment. Furthermore, the real-time functionality of the system provides the Mine with the capability to cease and re-commence mining operations in the event of having to work under, or in close proximity to, potentially hazardous mining conditions especially during the crucial period close to the end of life of mine. Lastly, the unit may also be deployed in areas where it is either too hazardous to install wall-mounted prisms, or alternatively, there is no access to the area of concern.
Figure 11. Geita Gold Mine monitoring network

Figure 12. Riegl laser scanner graphical output

Figure 13. GroundProbe radar unit at Geita Gold Mine, Tanzania

Figure 14. Reutech radar unit at Navachab Gold Mine, Namibia
The GroundProbe SSR-X system at Geita was commissioned with the express purpose of monitoring mining activities in the SW corner of the Nyankanga pit where the potential for a 90 m high x 200 m wide failure was identified in 2006. At the time, the area was being monitored by daily visual observations and automated surveys three times per shift. Unfortunately, the surveys were limited to the location of the prism stations that needed to be manually installed. A dearth of prisms (three) and limited access, requiring the use of a crane and man basket, meant that only 10% of the affected area requiring monitoring could actually be monitored. Use of a laser scanner was not deemed to be an appropriate monitoring technique due to the system not having a real-time functionality and not being sufficiently accurate to detect signs of a sudden, large-scale failure.

Graphic output from the slope stability radar unit procured to monitor the SW corner of the Nyankanga Pit, prior to the 2007 failure, is illustrated in Figure 16.

**Slope management at Geita Gold Mine—post-failure**

The deployment of new technology could not, and did not, prevent the failure of the south-western slope of Cut 4 in the Nyankanga Pit on 3 February 2007. What it did do, however, was ensure the safe and timeous evacuation of the pit prior to failure, ensuring that there were no injuries to personnel or damage to equipment. More than that cannot be asked of, or expected from, a risk management tool.

Going forward, the deployment of an integrated slope monitoring system has facilitated the successful, and safe, mining of the Nyankanga, Geita Hill and Star and Comet pits to date. Currently, ‘GeoMos’ prism monitoring is ongoing at the Nyankanga, Geita Hill and Star and Comets pits, specifically concentrating on movements associated with the soft oxide material during the rainy season. Reigl laser scanning is being concentrated within the Nyankanga Pit to
monitor the active mining areas, namely Cut 5 and Cut 6, while the SSR-X unit is focused on the Nyankanga footwall failure to facilitate the safe mining of areas characterized by voids and large, potentially loose boulders. Potentially hazardous areas identified within Nyankanga Pit and currently being monitored through the implementation of best practice and the integrated deployment of new technologies are shown in the Nyankanga Hazard Plan presented as Figure 17.

Conclusion

Given the increase in pit slope instability associated with the increase in open pit mining depths, the value of an appropriate risk management system cannot be overemphasized, as was illustrated by the 2007 Nyankanga Pit slope failure at the Geita Gold Mine in Tanzania. The primary benefit of an appropriate risk management system is the ability to monitor slope movement rates, the precursor to failure events. The ability to monitor slope movement rates in turn facilitates the identification of the onset of failure, typically through the acceleration of the movement rates. Once the onset of failure has been identified, it is possible to monitor the progression of the event over time and to make an assessment as to when the failure will occur, thereby creating the opportunity to safely and timeously evacuate personnel and equipment. In summary, the implementation of best practice and deployment of new technologies in open pit mining is a proactive, rather than reactive, approach to open pit risk management.

References

Geita Gold Mine Internal memoranda, slope monitoring data and hazard alert documentation.

GroundProbe Slope Stability Radar Brochure


Grey Dyke

Principal Engineering Geologist, SRK Consulting

Greg Dyke has been involved in the field of mining geology, hydrogeology, geology and engineering geology for the past 22 years (1987–2009) and has worked in the following countries: Saudi Arabia, Sierra Leone, Democratic Republic of Congo, Mali, Zambia, Tanzania, Guinea, Ghana, Zimbabwe, Botswana, Mozambique, Namibia, Swaziland, and Lesotho. He holds an MSc (Eng) (Mining Engineering) from the University of the Witwatersrand and is a Registered Professional Natural Scientist (PrSciNat). He is a Member of the South African National Institute of Rock Engineering and South African Institution of Engineering Geologists and served on the SAIEG Council from 2007 to 2008.

Greg has spent 18 of his 22 years in the consulting industry, having spent the first two years of his career as an underground section geologist, and more recently, 2 years as the Regional Geotechnical Engineer—Africa Region with AngloGold Ashanti Limited.