SLOPE MONITORING STRATEGY AT PPRUST OPEN PIT OPERATION

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ABSTRACT

Potgietersrust Platinums Ltd (PPRust) is Anglo Platinum's only open pit operation. The major slope stability concern at PPRust is rapid, small-scale brittle failure on the west wall of Sandsloot open pit. In order to improve safety and mine more economically, a comprehensive slope monitoring strategy has been implemented. In the last 3 years four new state-of-the-art monitoring systems have been installed namely an ISSI microseismic monitoring system, a GeoMoS automated prism monitoring system, prismless Riegl laser scanners and a GroundProbe slope stability radar (SSR). Groundwater monitoring and visual monitoring have also been improved over the same time period. To complement the visual inspections, SiroVision digital photogrammetry is now used for predicting where future failures may occur. All these monitoring tools provide primary monitoring which is used to identify high risk areas. The SSR is then set up in that area to provide early warning of failure so evacuation can be successfully done. Fault tree analysis has proved that with this comprehensive slope monitoring strategy the geotechnical risk at PPRust is greatly reduced, allowing mining to continue safely and economically in challenging conditions.

1. INTRODUCTION

Potgietersrust Platinums Ltd (PPRust) is Anglo Platinum's only open pit operation. It is located 35 km north of Mokopane (previously Potgietersrus), in the Limpopo Province of South Africa. It is situated in the centre of the northern limb of the Bushveld Complex, a saucershaped layered igneous complex. The northern limb hosts the Platreef orebody, which is a ~100 m thick tabular body that strikes north south, dips 45° to the west and reaches a depth of at least 1200 m (Figure 1). The Platreef is a PGM deposit and contains economic quantities of platinum, palladium, rhodium, gold, silver, copper, cobalt and nickel, which are all extracted and processed at PPRust.

Figure 1 Platreef geology in Sandsloot open pit

Sandsloot open pit opened in 1992 and is currently 2 km long, 600 m wide and 260 m deep. It is expected to operate until 2009 when it will reach a final depth of 300 m. In August 2002 a second open pit, Zwartfontein South, started up 1 km north of Sandsloot. It is 1 km long, 400 m wide and 100 m deep and has a life of mine of 20 years. Together the 2 pits annually produce 57 million tonnes of rock and 4.8 million tonnes of ore. A third open pit, Overysel, is due to begin operations in early 2006 and has a life of mine of over 90 years.

It is a given that rock slopes in an open pit will deform over time. The amount of deformation and the rate at which they deform are dependant on the geology, mining method and slope design. Slope movement does not need to hinder mining operations, however, if the failure mechanisms are understood and the slopes are properly monitored. This significantly reduces risk and it makes economic sense to install suitable monitoring systems in an open pit mine. This allows for more aggressive slope designs while maintaining safe working conditions for mine personnel. The cost of the monitoring equipment will usually be far outweighed by the extra revenue generated by the steeper slopes and the savings gained from fewer damages and injuries. This has been the case at PPRust where a comprehensive slope monitoring programme has been implemented over the last 2 and a half years.

In the last 3 years four new state-of-the-art monitoring systems have been installed at PPRust. An ISSI microseismic monitoring system was installed to monitor the footwall ramp in Sandsloot. GeoMoS automated prism monitoring system has replaced conventional methods. Prismless Riegl laser scanners have been installed to provide coverage in areas where prisms could not be maintained. A GroundProbe slope stability radar (SSR) was acquired to provide early warning of rapid brittle failures. Groundwater monitoring and visual monitoring have also been improved and crack meters are now installed wherever dangerous tension cracks are identified. To complement the visual inspections, SiroVision digital photogrammetry is used for predicting where future failures may occur. As shown in Figure 2, most of these monitoring tools provide primary monitoring which is used to identify high risk areas. The SSR is then set up in that area to provide early warning of failure so evacuation can be successfully done. Fault tree analysis has proved that with this comprehensive slope monitoring strategy the geotechnical risk at PPRust is greatly reduced, allowing mining to continue safely and economically in challenging conditions.

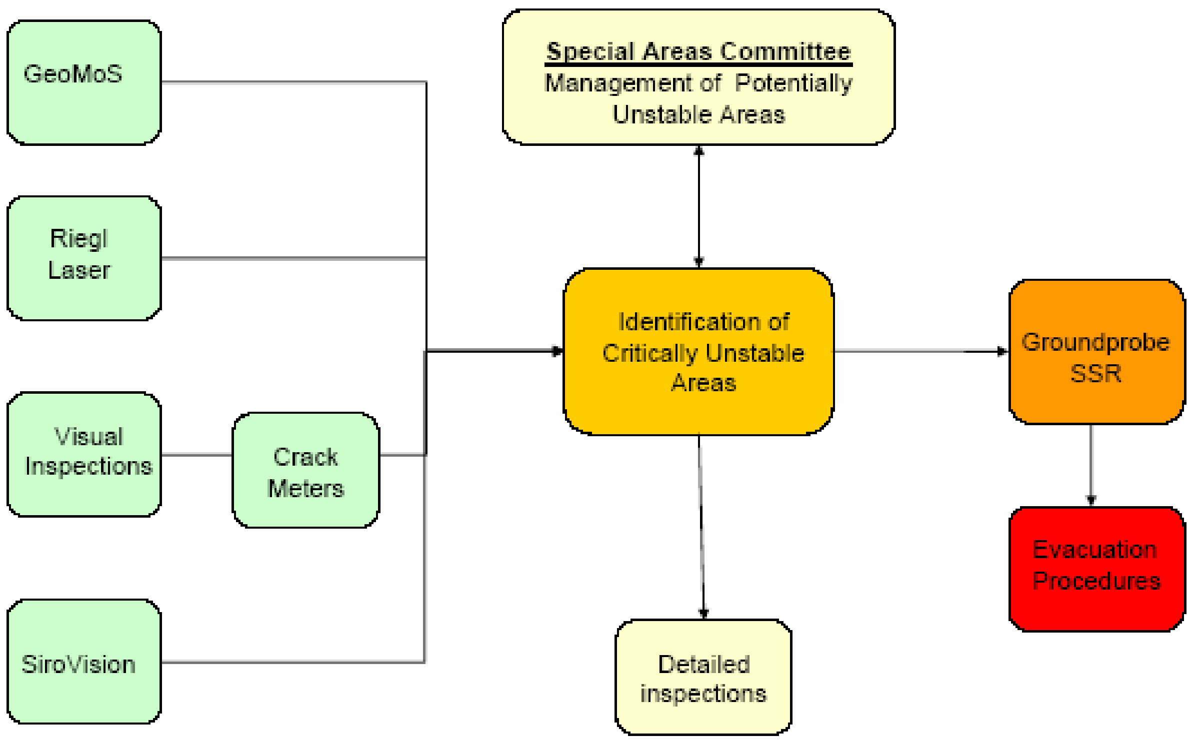

Figure 2 Slope monitoring strategy at PPRust

2. SLOPE STABILITY

The main slope stability concern at PPRust is stack failure on the western wall in Sandsloot open pit. These failures are a result of a large-scale fault zone that cross-cuts the entire west wall (Little, 2005). The 150 m wide fault zone hosts many faults spaced 5 m apart and joints spaced 20-50 cm apart which dip out of the face at roughly 55 degrees (Figure 3). Each one of these structures has the potential to cause failure. The failure mechanism is a combination of loss of cohesion on these planes and shearing through the rock bridge as a result of blasting. The failures are rapid brittle failures that occur in less than 2 hours and are of the order of tens to a few thousand tonnes.

There is potential for the same problem on the Zwartfontein South western wall. However the other joint sets are more prominent and significantly reduce the size of potential failure. The eastern walls in both pits are fairly stable. Sandsloot is on its final cutback and thus all walls are permanent and long term slope stability is important. Zwartfontein South is on an intermediate cutback and thus the short term slope stability is more important. The slope monitoring systems at PPRust thus focus on the Sandsloot west wall however all areas are taken into consideration.

Figure 3 Photograph of fault zones cross-cutting the west wall of Sandsloot open pit.

Slope stability monitoring at PPRust is the responsibility of both the Survey and Rock Engineering departments. The operations managers have a responsibility, however, to ensure that their staff has a certain level of awareness and that evacuation plans are in place and have proven effective. Training of all mining personnel in basic slope stability and regular evacuation drills are performed to achieve this. The first 'line of defense' in slope monitoring is visual inspections. The pit foremen and superintendents perform visual monitoring at the start of each shift and note their observations in the shift logbook. The geotechnical assistant also does daily visual inspections in operational areas and these observations are passed on to mining personnel.

3. PRISM MONITORING

Conventional prism monitoring, found at most open pit mines worldwide, was performed by surveyors from 1997 to 2003 at PPRust. In October 2003 three automated theodolites were installed to save time, increase the number of measurements and improve the accuracy and precision. Prisms are installed on the highwalls at a regular spacing, 50m horizontally and 45m vertically, and on critical areas throughout the open pits (Figure 4). The Survey Department is responsible for maintaining the theodolites and prisms and for collecting and storing the data. The rock engineers then analyse the data, looking for significant movement, and report any potential areas of slope failure to the mining personnel.

The prism positions are measured every 4 hours by the automated theodolites, two of which are permanently set up on beacons on the western and eastern crests of Sandsloot open pit. The third theodolite is set up on the crest of eastern wall of Zwartfontein South but is moved to the western wall at night. The theodolites are housed in a steel structure to protect them from flyrock, harsh weather conditions and theft. The data is sent, as it is captured, via radio link to an office computer in the Survey office where it is stored in the GeoMoS software program (Leica Geosystems, 2005).

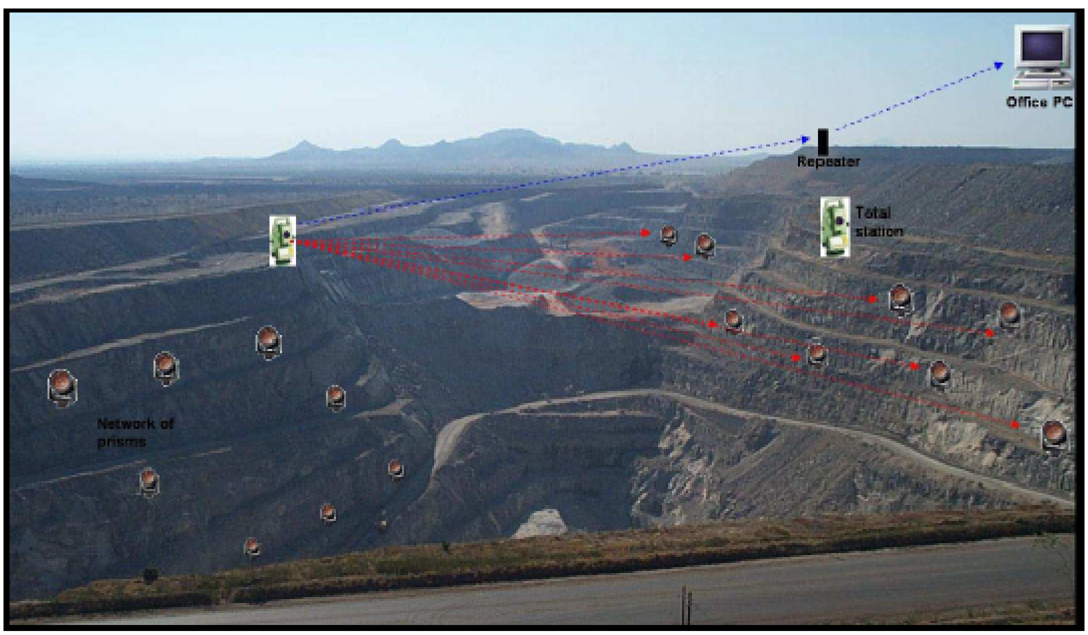

Figure 4 Prism network and monitoring setup in Sandsloot open pit

The GeoMoS system monitors the status of the total stations and allows the user to view the data graphically. The user can filter the data and plot graphs of displacement, velocity and vector movement of one or many selected prisms. There are 3 displacement plots – longitudinal (Figure 5), transverse and height - for the movement along the x, y and z axes. A vector plot combines these 3 movements into an absolute movement. A velocity plot uses the longitudinal displacement to calculate a displacement velocity. All the graphs can display raw or smoothed data and system errors can easily be identified as seen in Figure 5. The data from the prism monitoring is automatically stored in a customised MS Access database called SSMON. It is linked to the mine's draughting package, AutoCAD, which displays the movement vectors on cross-sections or 2D plans.

The GeoMoS Analyser graphs are plotted automatically whenever new data is received which enables quick and easy identification of slope movements. Alarms are set by the rock engineers at site-specific trigger levels and sms's are sent out to the Survey manager when those levels are exceeded. At PPRust the alarms sound when 30mm displacement or 50mm/2 hours velocity is recorded. If an alarm is sounded, the Survey department will check that it is not a result of survey error while the Rock Engineering department will investigate the area of concern. If slope movement occurs in a working area it will be evacuated until it is declared safe. Laser and radar monitoring will be set in place to improve monitoring until the slope fails. Alternatively failure is induced to remove the risk completely so that operations can continue safely.

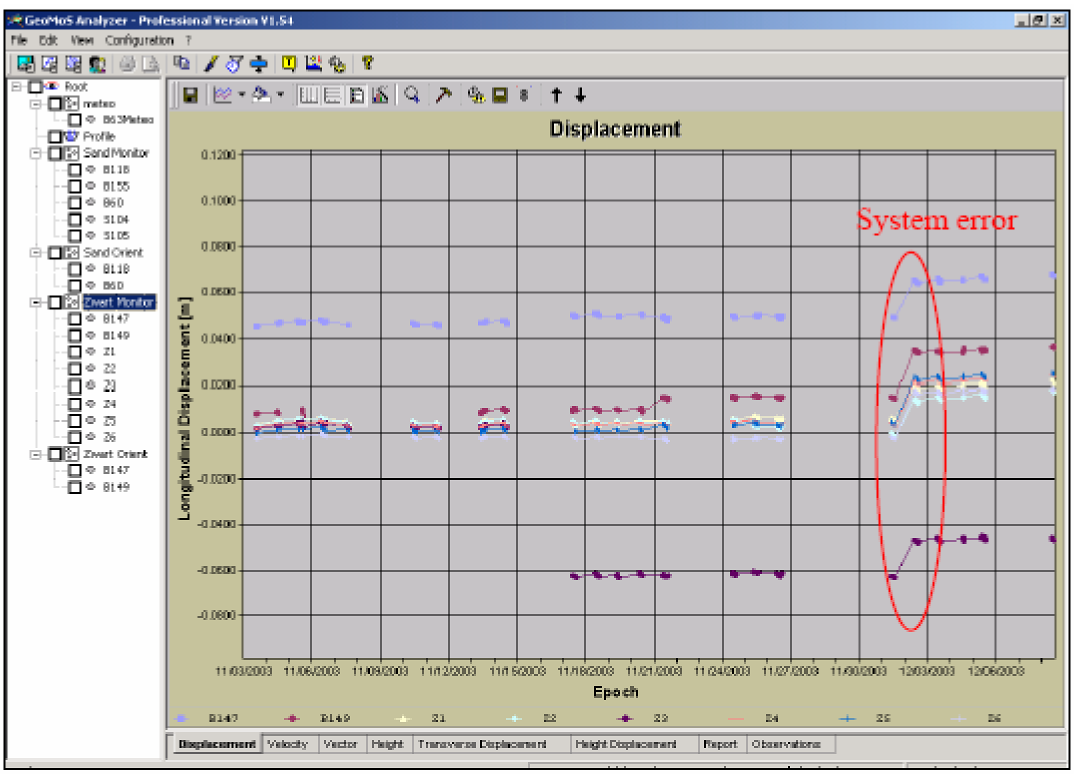

Figure 5 Longitudinal displacement plot in GeoMoS Analyser showing a system error

The failures recorded so far on the west wall have occurred very rapidly (under 2 hours) and the prism monitoring has not been able to provide warning of failure for evacuation purposes. Thus the GeoMoS system is used at PPRust for identifying long term slope movement trends and indicating where slope failure is more likely to occur. The response to slope movement is thus to declare a Special Area, perform detailed inspections and install other monitoring devices.

Even though prisms are securely installed and a steel protective casing is fitted around the prism, many prisms are damaged or lost due to rockfall, slope failure and flyrock. The west wall in Sandsloot is especially difficult to maintain prism coverage due to the regular bench failures which results in loss of catchment berms and therefore loss of access. The prism installation can also be dangerous and it is time consuming and expensive. Prism monitoring is also limited by the fact that it measure movements of single widely-spaced points on a slope. There is the possibility for a failure to occur between the points without it being recorded. As a result of these limitations, the Riegl laser a nd GroundProbe radar monitoring systems have been implemented at PPRust.

4. LASER MONITORING

Prismless laser monitoring was introduced at PPRust in February 2005 to fill in the gaps where prisms have been lost or where they were never installed. Two Riegl LPM-2K laser scanners (Riegl, 2005) for slope monitoring are permanently installed in steel protective houses on the crest of the eastern highwalls in both Sandsloot and Zwartfontein South open pits (Figure 6). The laser scanners are battery operated, require no levelling and are eyesafe under all operating conditions. A camera is attached to the side of the laser and takes photographs at the start of scanning.

The lasers are controlled by 3DLM Site Monitor software which allows the user to specify monitoring points and frequency as well as group certain points. The exact x, y and z coordinates of specified points are programmed into Site Monitor and these points act as ‘virtual prisms’. In Sandsloot these points are spaced 5 m apart, both horizontally and vertically across the entire 2 km long and 100 m deep slope. The wall is divided into 10 zones and the laser scans the points one by one and returns to the first point at 6am every morning and 6pm every evening. It takes 9 hours to scan the entire west wall which is 500 m to 1 km from the scanner (depending on the angle). The accuracy is 20-50 mm which is comparable with GeoMos.

The laser transmits the data by radio to a computer in the Survey office where the data is downloaded into Site Monitor Analyser and PolyWorks software where the data can be analysed. The data appears as a point cloud (Figure 7) which can be rotated, filtered and coloured as required. The data can be exported in ASCII format thus can be brought into AutoCAD and Datamine.

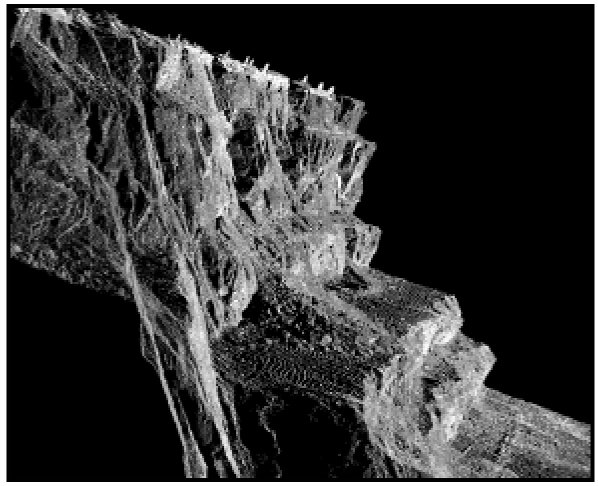

Figure 6 Laser installation

Figure 7 laser point cloud showing a side view of a pit slope

The point clouds are very useful for volume calculations and visually analysing the state of the pit slope. More importantly, the point clouds are compared, point by point, and progressive slope movement is calculated and plotted. A photograph of the scanned region is displayed and the movement is overlaid in various colours. Contour plots can be made of the movement data and alarms can also be set up as with the GeoMoS system. Laser monitoring, however, has the same disadvantage as the prism monitoring in that it cannot provide early warning of failures for evacuation purposes. It is therefore also used for long term monitoring trends and for identifying high risk areas where the GroundProbe radar must be put in place.

4. RADAR MONITORING

The GroundProbe slope stability radar (SSR) was implemented at PPRust in November 2003 to monitor the Sandsloot west wall (Figure 10). Previously recorded failures were of the order of tens to a few thousand tonnes and appeared to occur instantaneously. The SSR scans a 10,000 m^2 area in one minute and thus can provide early warning of any failure for evacuation purposes. It scans the west wall 24 hours a day, in all weather conditions from a position on the crest of the east wall.

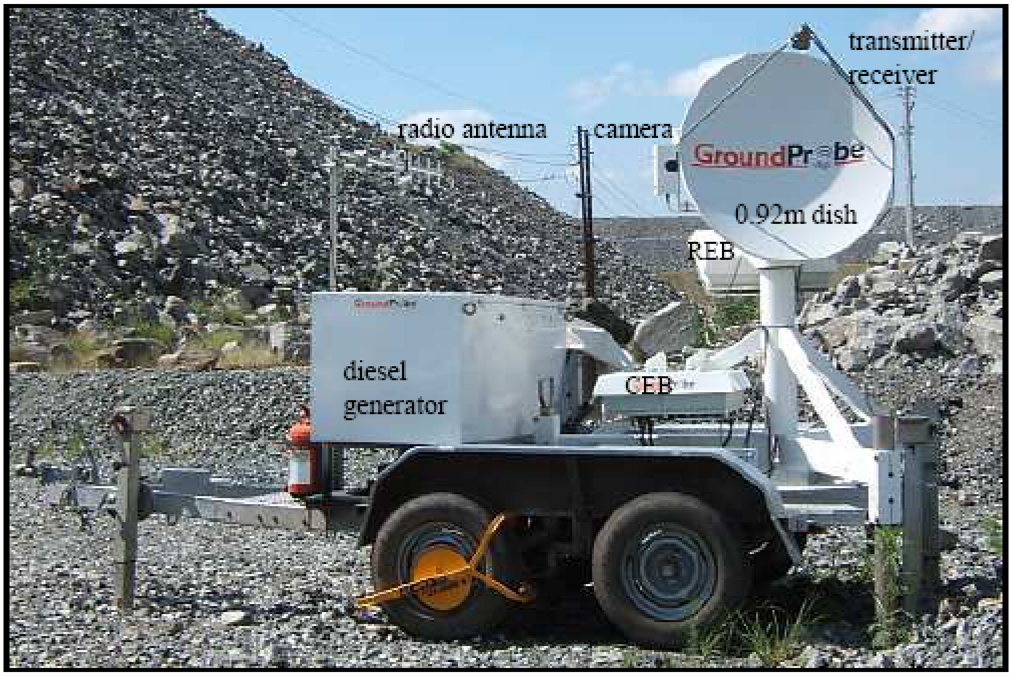

Figure 8 The GroundProbe Slope Stability Radar (SSR)

The SSR scanning antenna consists of a 0.92 m parabolic dish mounted on a sturdy tripod and controlled by motors and gears for horizontal and vertical movement. A diesel generator is housed at the back of the trailer and it powers the mechanical movements of the dish as well as the electronic equipment. The SSR is a mobile system that can be relocated in roughly an hour. A camera is fixed to the dish and photographs can be taken whenever required. Once set up and turned on, the SSR takes 14 photographs which it converts to a mosaic of the entire area that it can see and scan. The operator then selects a 2D scan area on the slope and scanning begins (Figure 9). The scan time is dependant on the size of the slope area selected and the distance from the slope. The range on the SSR is 850 m however that can be doubled if a 1.8 m dish is installed. An atmospheric region is selected on the scan region which is used to compensate for atmospheric disturbances caused by local changes in pressure, temperature and humidity.

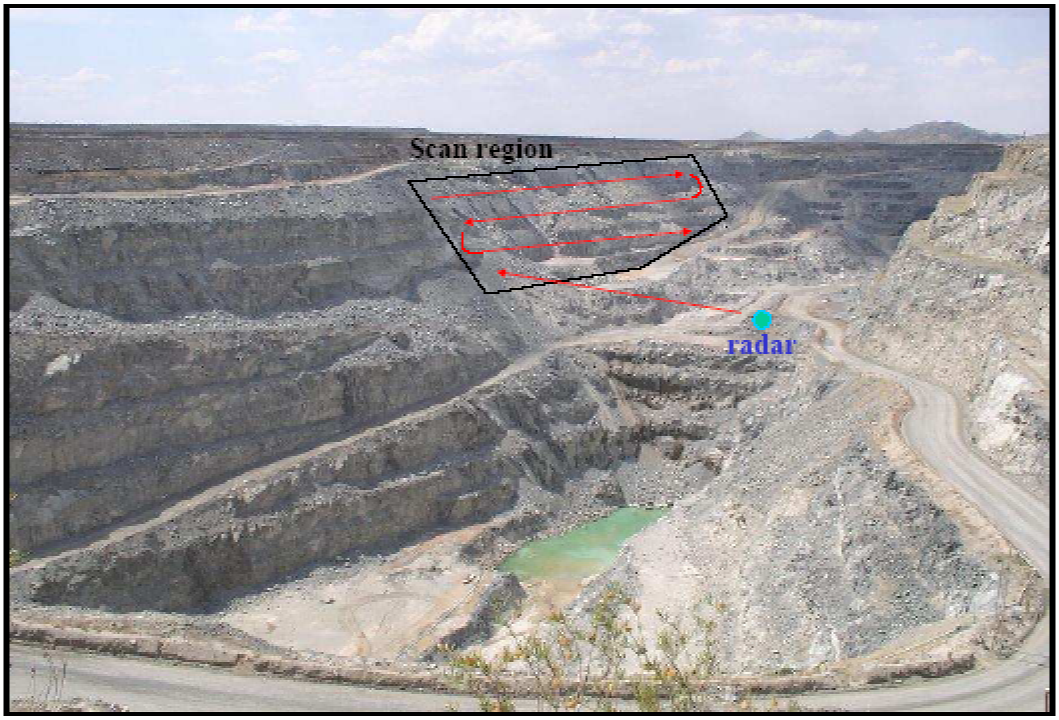

Figure 9 An example of the radar setup in Sandsloot open pit

The SSR uses differential interferometry to measure sub-millimetre movements on a rough rock face (GroundProbe, 2005). It does this by comparing the phases of the radar signals it receives from one scan to the next. Any phase difference that it records is converted to a measurement in millimetres. It displays this information on a computer screen as a pixelated 2D image using hot and cold colours to indicate movement (Figure 10). The hot colours indicate movement out of the face and cold colours indicate movement away from the face – i.e. rocks have fallen out of the face. The most recent photograph of the scan area is shown next to the 2D image so that the operator can see where the movement is occurring on the slope. The operator can choose what time period (since the scanning started) to view as well as what level of movement to colour the plot on. At PPRust rapid brittle movements are monitored thus the maximum movement (red) is set at 15mm. Any number of deformation versus time graphs can be plotted on any area in the scan to make the interpretation of the data simpler. This will show the deformation history of a particular area. The operator can zoom in on the graphs as well as on the photographs and the deformation plots.

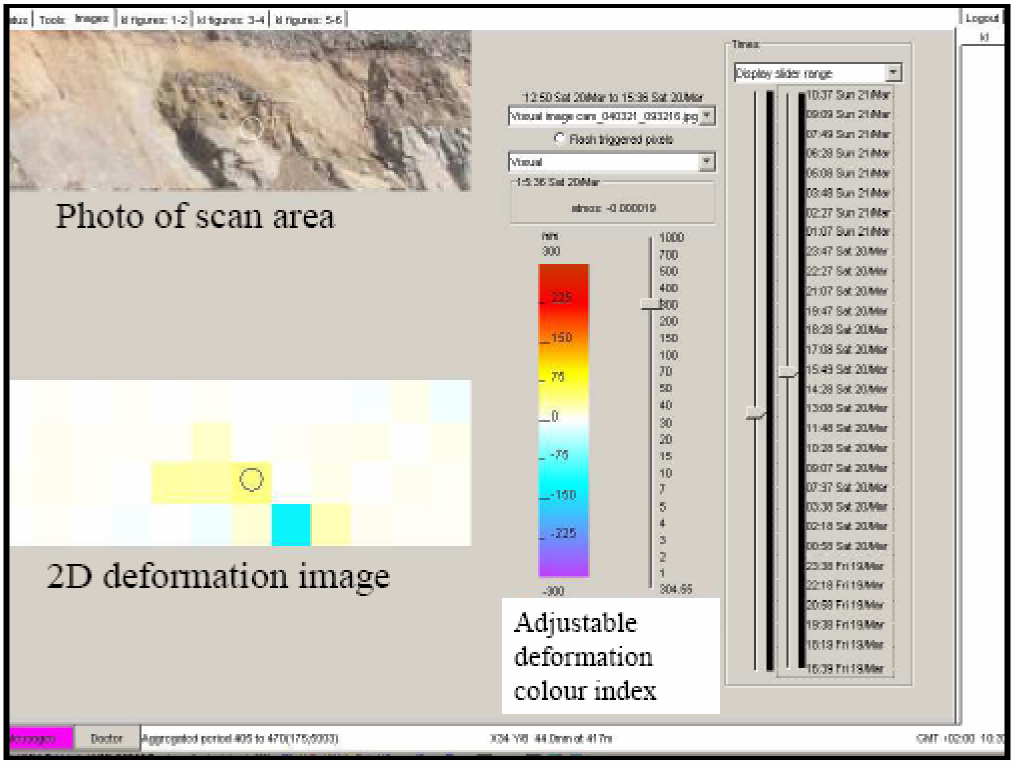

Figure 10 SSR viewing screen which shows a photograph of the scanned area, 2D deformation image, colour scale and time scale.

Customisable alarm settings and masking options are also available and the operator can select the amount and speed of movement that is considered indicative of failure. The operator can also mask out areas that could cause false alarms for example where trucks and shovels are operating or where loose material is situated. The operator can set red and orange alarms. The orange alarms are there to alert the rock engineers to a potential problem while the red alarm is considered urgent and evacuation of the risky area in the pit follows. After a 2 month trial period at PPRust, the red alarms were set at 10mm of movement over 2 hours and an area of 80 m^2. The area varies according to distance of the radar from the wall while the deformation is so small because the SSR measures the deformation of the rock face in the direction of the SSR.

When movement does exceed the set limits then a red flashing alarm screen appears with instructions on what the operator must do. At the same time, sms's are sent out to all members of the geotechnical department. At PPRust, a siren with red lights is set up in the working area in the pit that is being monitored by the SSR. It is linked to the computer in the Control room and goes off when a red alarm sounds. This ensures that the workers are notified of imminent failure and can evacuate without the communication from the control room.

Eight brittle failures have been recorded in Sandsloot with the SSR and they all show that the slope movement occurs over less than 2 hours (Figure 11). This gives the operations staff very little time to respond – in some cases only 20 minutes. The SSR does provide early warning and people and equipment have been successfully evacuated at PPRust as a result. It is evident that at PPRust the SSR is the only monitoring tool that allows mining operations to continue safely under the high risk west wall in Sandsloot.

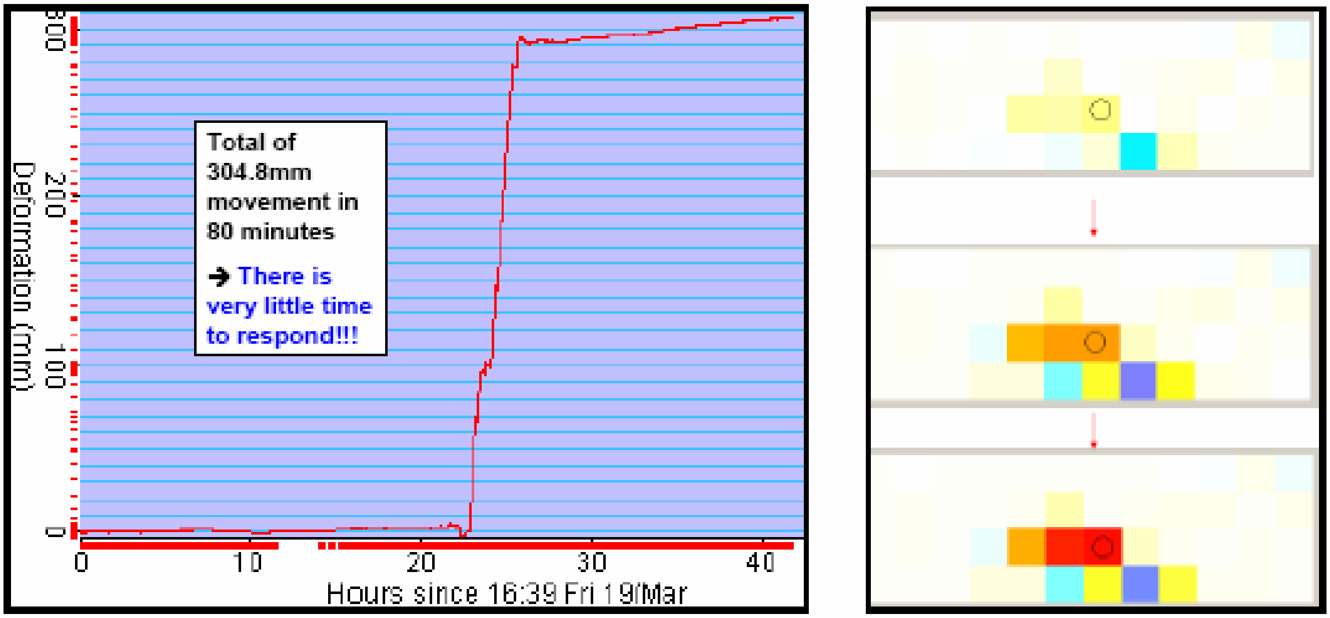

Figure 11 a) SSR deformation versus time plot of rapid brittle failure b) successive deformation images with change in colour showing the progressive movement

It is imperative therefore that the SSR is placed in the correct position at all times. Generally it sits in the middle of the crest of the eastern highwall and monitors 70% of the west wall. When drilling is done adjacent to the west wall the SSR may be moved closer or to a better position. As discussed, the GeoMoS and Riegl laser are used to indicate higher risk areas where the SSR must monitor, but another tool, SiroVision, is also used for this purpose.

5. DIGITAL PHOTOGRAMMETRY

SiroVision is a digital photogrammetry software program that enables safe and comprehensive mapping of dangerous and inaccessible highwalls (Poropat, 2001). Large areas can be quickly mapped and it provides an excellent record of the changes in pit faces over time. A normal high resolution digital camera is set up on a tripod and its position is surveyed. A photograph is taken of the face in question, which must include a surveyed reference point of some sort. The tripod is moved a certain distance (e.g. 50m) to the left, its position is surveyed and a second photograph is taken of the same face

(Figure 12). The distance depends on the distance from the camera to the face and the 2 photographs must overlap by 90%. This can be repeated for all the areas on the slope. The photographs are downloaded from the camera and are brought into the software along with the survey readings.

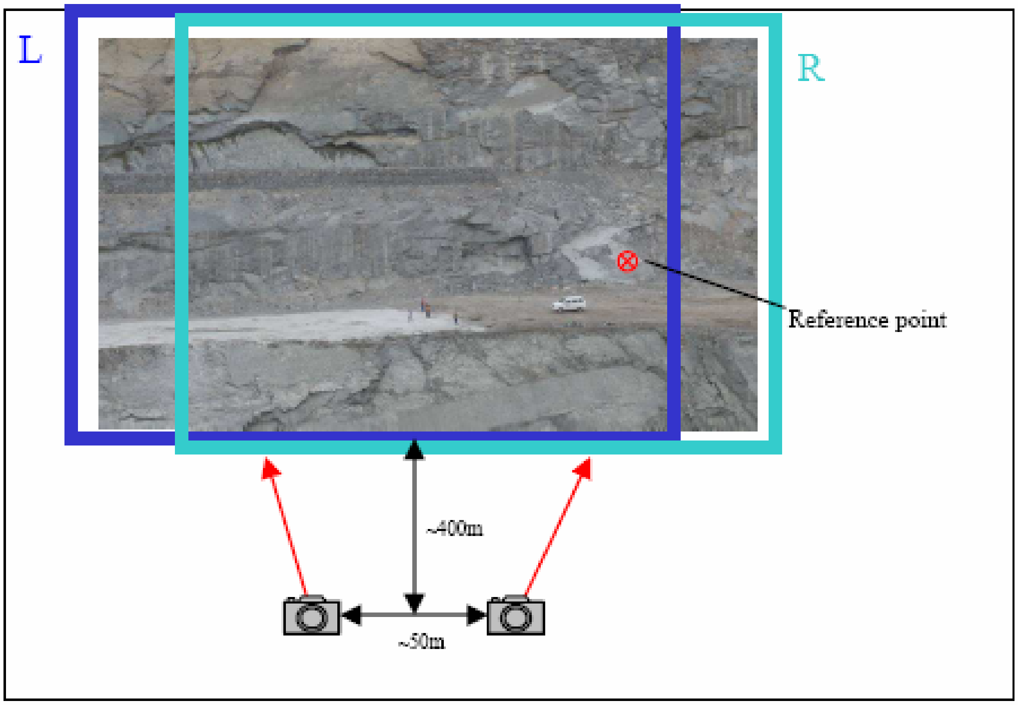

Figure 12 Method of obtaining photographs for SiroVision

SiroVision is made up of 2 parts – Siro3D and SiroJoint. Siro3D is used to import the images and surveyed coordinates, which are then combined and converted into a 3D image which is accurate to 1 degree orientation. The 3D image is made up of 2 parts – a 3D point cloud and a 3D photograph. The images are saved and then opened in SiroJoint which is used to interpret the images. Joints, faults, dykes and geological contacts can be easily digitised in SiroJoint and orientations (dip and dip direction) can then be measured off the image (Figure 13). These readings will often be more accurate than ones taken in the field as they average hundreds points on the whole surface. When a geologist takes a reading he measures only a few points on a large surface. Also many of the flat lying joints in a mapping face cannot be reached by a geologist thus the mapping data is biased towards the vertical structures. With SiroVision however, all structures in a face can be measured thus the bias is removed.

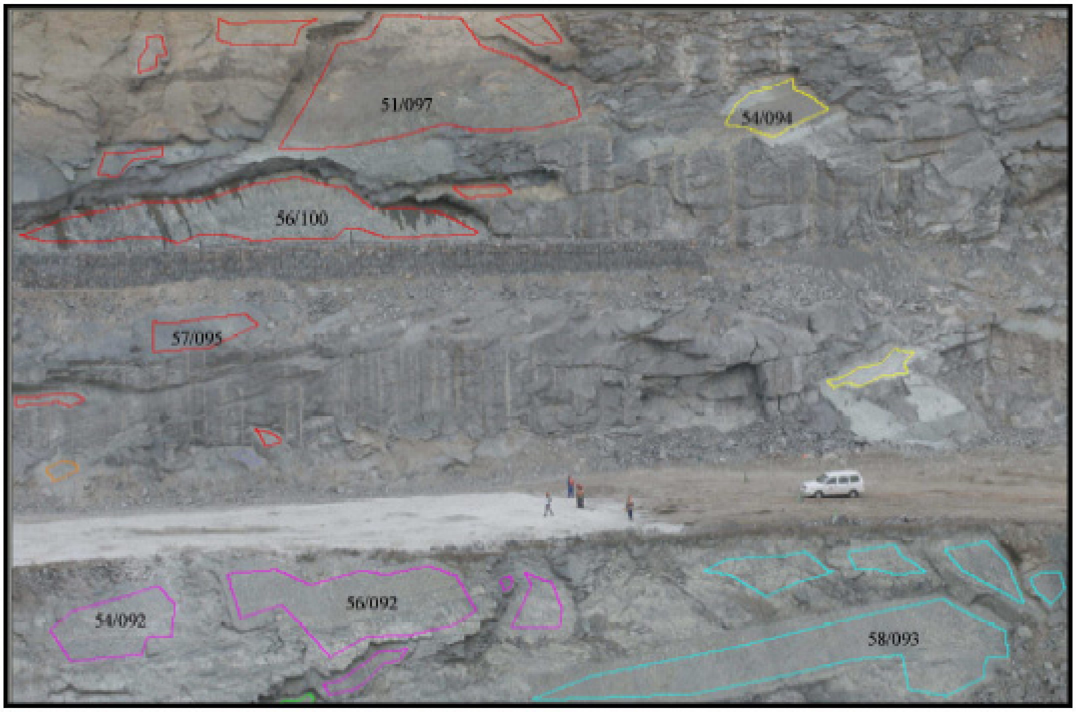

Figure 13 Dip and dip directions of a number of joints read off the SiroVision 3D image

The orientation readings can be plotted on stereonets in SiroJoint and grouped into joint sets. At PPRust, this is used for joint set identification, kinematic failure analysis and geotechnical zoning. The structures can be extrapolated and overlaid over pit designs in SiroJoint or exported into design and draughting packages. It greatly improves the rock engineer's ability to identify potential failure planes in 3D space and to predict where they will cause failure on the benches below. This is particularly effective on the west wall at Sandsloot open pit where there is no access to faces and mapping the accessible faces is dangerous. Also the size of the exposed failure planes ensures reliable readings and allows for accurate extrapolation. The west wall is regularly mapped with SiroVision and each failure plane and potential failure plane is exported into Datamine. The planes are then extrapolated laterally and downslope to provide an idea of where failures may occur on lower benches (Figure 14). This enables better identification of where prisms must be installed, laser point cloud density must be increased and radar monitoring must be focussed. It also provides a qualitative method of monitoring failures. By taking photographs of the same place on a regular basis comparisons can be made and failures that have been missed by other monitoring techniques can be identified. SiroVision analysis also aids the planning department in designing around the failures and incorporating the cost of cleanup and secondary blasting into their economic analysis. It is therefore important for the Rock Engineering department to work closely with the Survey, Geology and Planning departments to get the maximum benefit out of the system.

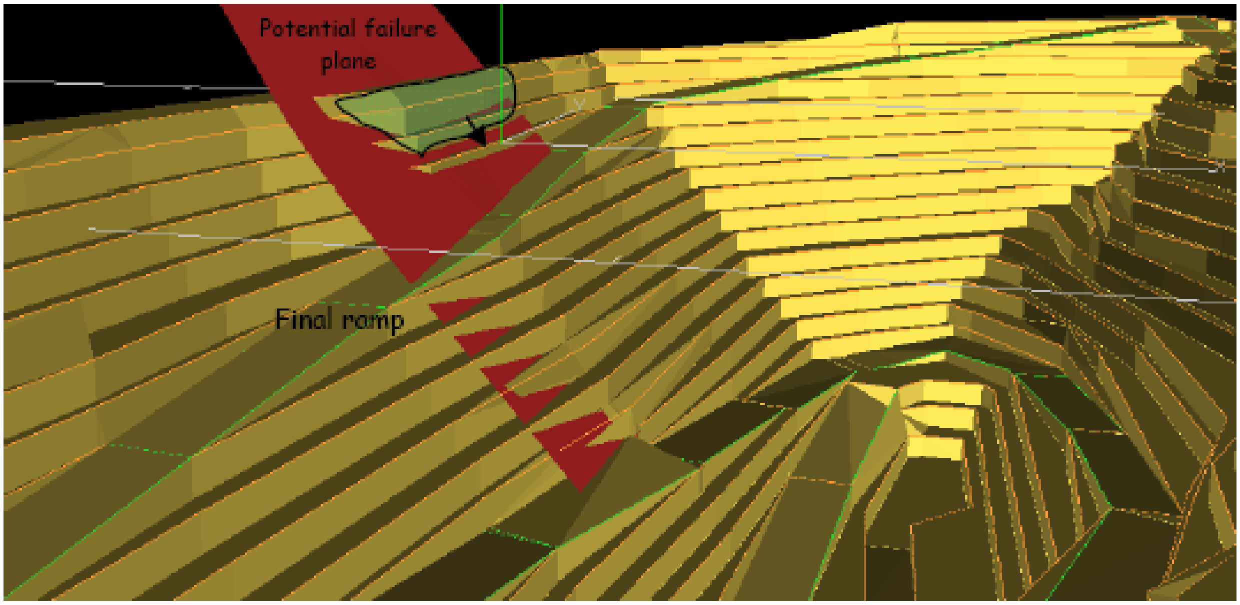

Figure 14 Failure plane measured in SiroJoint imported in Datamine and extrapolated on lower benches and ramps for stability analysis

6. VISUAL MONITORING

Visual monitoring, like SiroVision, plays an important role in identifying high risk areas and subsequently implementing the correct monitoring systems. A system is only as good as its user and without inspections by geotechnical staff and operational staff the monitoring equipment would be incorrectly used. Inspections are also a basic form of monitoring and are especially important in areas that do not warrant high-tech monitoring devices. The geotechnical department at PPRust performs 4 types of inspections which are stored in a MS Access database.

Daily inspections on operational areas are done by the geotechnical assistant and any hazards that are identified are reported immediately to the mining personnel who are then responsible for taking action to remove the risk. These are very simple inspections which the pit foremen can also perform.

Detailed inspections are done on areas that are high risk or where failure has occurred. These provide good understanding of the causes of failure and enable the geotechnical engineers to select the correct monitoring devices for the hazardous area.

Comprehensive monthly inspections of all areas in both pits are done by a rock engineer who uses the data to determine risk ratings for each area. A monthly hazard plan is produced which is displayed in all shift change and line up areas so that all pit personnel are aware of the risk levels in their area. Mitigating actions are also specified and the pit superintendent is responsible for implementing them.

Presplit inspections were designed to measure the success of the presplit and trim blast designs. The blast design parameters and the condition of the highwall are combined to calculate a rating out of 10 for the presplit wall. This enables the rock engineers and blast engineers to determine the cause of damaged final walls and remedy the problem ahead of further blasts. The ratings are also automatically overlaid on bench plans in AutoCAD which are accessible to all mining personnel. Thus at any time, a user can check up on the status of the highwalls. Presplits and trim designs are thus regularly checked and improved.

7. SEISMIC MONITORING

Seismic monitoring aims to predict slope deformation by measuring microseismic events caused by brittle movements within a rock slope. Analysis of microseismic events using multiple geophones enables the location of source and therefore the discontinuity on which movement is occurring. Seismic monitoring systems are the norm in underground gold mines but have only recently been implemented at open pits by ISSI. These systems consist of a number of geophones installed in the pit slope (Figure 15), which record all microseismic movements down to 0.001mm. The data is stored on a hard disk on surface and collected or sent to an office computer via radio link. The data is then interpreted by seismologists and reports are produced. Increased seismic activity can provide early warning of slope failure and trends in the data can potentially identify weak failure planes. Navachab open pit found that the system gave them 6 weeks warning of a large slope failure prior to prism movement (Lynch *et al.*, 2005). It is therefore a long-term monitoring system for which aids in the understanding of weaknesses in a rock mass.

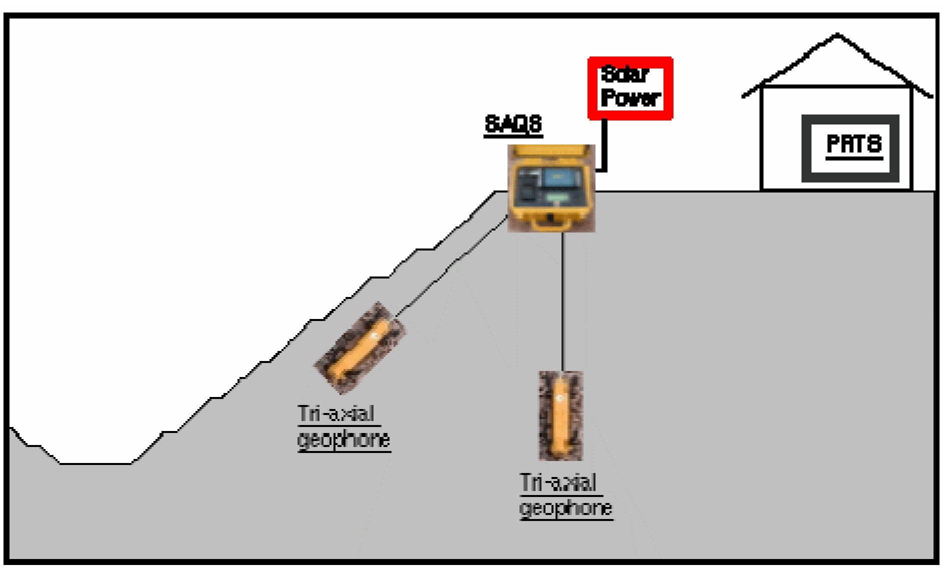

Figure 15 Sketch showing the setup of a seismic network in an open pit (ISSI website)

A 4-geophone ISSI system was installed in the eastern slope of Sandsloot in May 2003. Monitoring began on a trial basis with the view to provide long-term monitoring of the slope above the permanent footwall access ramp. Seismic monitoring continued until June 2005 and monthly reports were issued by ISSI. Monitoring ceased as less than 10 microseismic events were being recorded a month and the rock engineers agreed that the wall was very stable and did not warrant the expensive ISSI system.

8. GROUNDWATER MONITORING

PPRust receives about 350 mm of rainfall a year. The groundwater flow is from NE to SW and is structurally controlled. It therefore does not pose a major slope stability problem but is very difficult to manage. Dewatering methods such as toe drains and pumping have produced poor results and the current strategy is to regularly measure the piezometers installed around the pits, to maintain trenches on the pit perimeters and to continue pumping from sumps on the lower benches. Rainfall gauges are checked daily and piezometer readings are taken once a week. This data is stored in the SSMON database and can be displayed on cross-sections in AutoCAD.

9. FAULT TREES

A fault tree (Figure 16) is a graphical framework that is used to estimate the probability of occurrence of an undesirable event such as a fatality, damage to equipment or economic loss (Anon., 1999). The framework, or fault tree, illustrates the sequence of events that led to the undesirable event, and probabilities of occurrence are assigned to each event by a group of experts. It is a powerful tool as it highlights where the problems are and how one can reduce the risk of an event as serious as a fatality. The fault tree quantifies the risk and enables management to make informed decisions on the level of risk they are willing to operate at.

At PPRust, detailed fault tree analysis was done in order to quantify the risks posed by the failures on the western high wall of Sandsloot open pit. The fault trees were designed to calculate the probability of a fatality as a result of bench, stack or overall slope failure. The design of the fault tree and the numbers assigned, were agreed upon by the rock engineers at PPRust, the head office consulting rock engineer and SRK consultants. The probabilities of failure were calculated using FLAC and Slide. They were then adjusted to take into account operational conditions, such as wet slopes and the impact of blasting. The sequence of events used was as follows: start of slope failure; primary monitoring identifies possible failure; radar gives early warning of failure; evacuation; fatality. The primary monitoring includes GeoMos, laser and visual inspections. For each event, the probability of the effectiveness and ineffectiveness (their sum being 1) was assigned. The idea is that if any of the steps in the process were ineffective then a fatality would occur if people were working in the area. The total probability of fatality for 100% human exposure is calculated using the Total Probability Theorem (Papoulis, 1984).

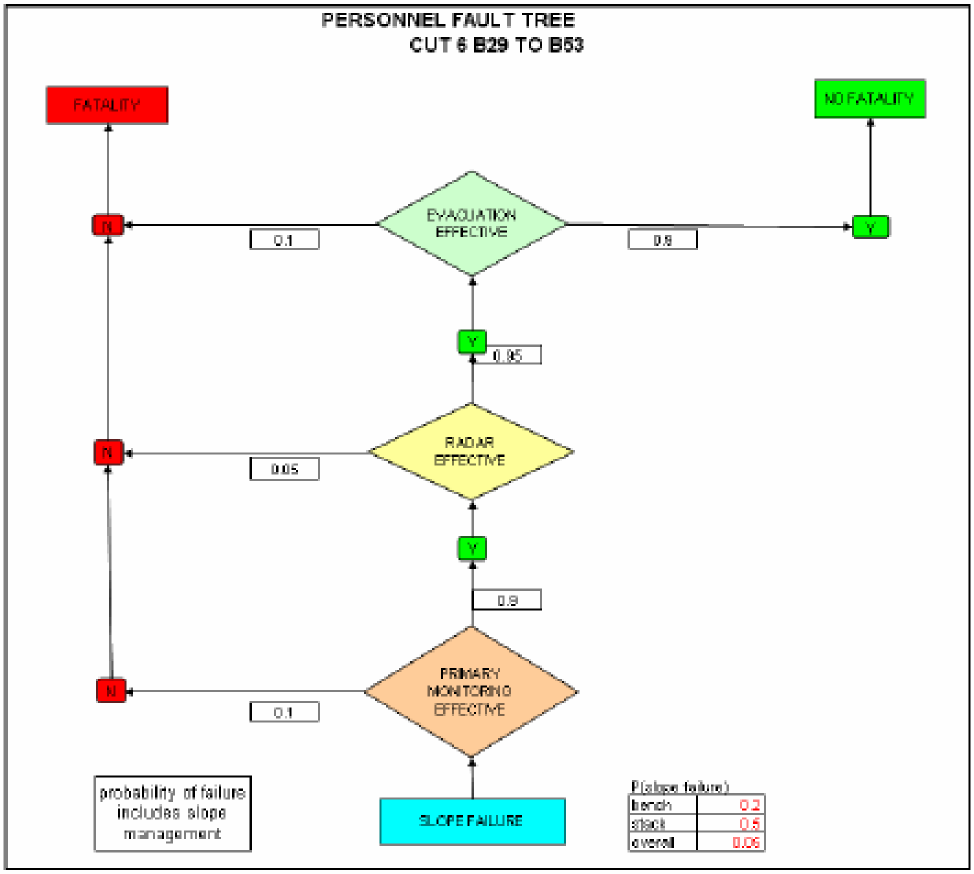

Figure 16 Fault tree design for Sandsloot open pit

The annual human exposure was calculated using mining rates for the west wall. The exposure is then multiplied by the probability of fatality at 100% exposure. This probability was then compared to an internationally acceptable level of risk. A number of countries have calculated acceptable risk and Anglo Platinum has chosen the most stringent figure of 1 in 10 000 as its acceptable level of risk.

Various fault tree scenarios were run to determine the effect that improved monitoring techniques as well as improved evacuation, dewatering and wall control would have on mitigating risk to personnel at Sandsloot. In particular, the effect of the GroundProbe slope stability radar was studied. Results showed that the slope stability radar significantly reduced the safety risk thereby making it an essential part of the slope monitoring and risk management programme at PPRust. It also highlighted the importance of primary monitoring and efficient evacuations. Without any sophisticated equipment an open pit mine can significantly reduce risk merely by improving the evacuation technique and visual inspections, both of which are inexpensive. Human exposure, and thus probability of fatality, can also be reduced by intelligent mine planning and the use of safer mining equipment.

9. CONCLUSIONS

Over the past two and a half years a comprehensive slope stability monitoring programme has been implemented at PPRust. The prism monitoring was automated in 2003 using GeoMoS to analyse the data and produce alarms. Due to the brittle failures on the west wall in Sandsloot many prisms were lost and many areas could not be accessed thus the Riegl laser system was installed in 2005 to measure 'virtual prisms' on that area. Due to the rapidity of the failures, it was determined that the GroundProbe slope stability radar (SRR) was the only monitoring device that could provide early warning of failure on the west wall. Thus a SSR was purchased in August 2005 after a successful lease period of 22 months. Eight failures were recorded with the SSR and showed that the pit personnel have less than 2 hours warning before failure occurs. The ISSI microseismic monitoring trial was not as successful and was terminated in June 2005 after 2 years in which no significant movement was seen. Piezometers were installed in January 2005 to better monitor the groundwater and its influence on slope stability.
Daily inspections of operational areas by the geotechnical assistant began in 2004 and they ensure that the pit personnel are always aware of the slope stability hazards. Hazard plans were also generated using monthly pit inspections and they graphically show the pit staff where the slope stability hazards are predicted to be in the coming month. Presplit inspections were also implemented in 2004 and they allow the rock engineers to measure the effect of blasting on the slope stability.

Fault tree analysis allowed the geotechnical department to describe geotechnical hazards as geotechnical risks to the company which enabled management to make an informed decision, based on risk, 22 on final slope designs. It showed that there are many simple ways to reduce geotechnical risk. For PPRust however, high tech equipment as well as aware, trained workers, are essential to the safe mining on the west wall of Sandsloot open pit.

PPRust aims to use all available, relevant monitoring technology at its disposal to ensure that the risk posed by deforming rock slopes is kept to a minimum. It is also recognizes that people play an important role in slope monitoring and thus all pit personnel at PPRust are trained in slope stability. Also, regular inspections are undertaken to ensure that no hazards are overlooked. With this slope monitoring strategy PPRust can continue to operate safely in challenging geotechnical conditions.

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