

INSTITUTE OF QUARRYING

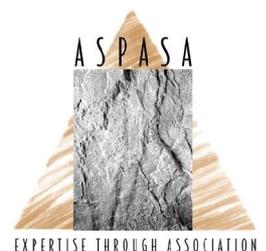
SLOPE STABILITY RISK MANAGEMENT AT ANGLO PLATINUM'S SANDSLOOT OPEN PIT

By

Alan Bye, Geotechnical Engineer, Anglo Platinum
**Megan Little, Rock Engineer, PPRust, Anglo
Platinum**
**Desmond Mossop, Manager Rock Engineering,
PPRust, Anglo Platinum**



36th ANNUAL CONFERENCE & EXHIBITION
Birchwood Conference Centre,
Gauteng
3-5 MARCH 2005





INSTITUTE OF QUARRYING SOUTHERN AFRICA
Incorporating ASPASA
36TH CONFERENCE & EXHIBITION – 3-5 MARCH 2005



‘SLOPE STABILITY RISK MANAGEMENT AT ANGLO PLATINUM’S SANDSLOOT OPEN PIT’

Author/Speaker:

Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining and Geological Services

Alan Bye graduated from the University of Natal, Durban in 1997 as an Anglo Platinum bursar and subsequently, during part time study, obtained a PhD in engineering geology (2003). He has published and presented over 25 papers in a series of international journals and conferences on applied engineering geology and open pit mining. Alan has received numerous awards for his geotechnical research and is a regular lecturer at the WITS university mining engineering department.

Alan has had experience in exploration and production geology, open pit geotechnics, drill & blast engineering and water resource management. Alan gained the majority of his experience at Potgietersrust Platinum where he was ultimately employed as the Operations Manager. He has also served as an open pit geotechnical consultant for SRK Consulting Engineers.

Currently he is employed as a consulting geotechnical engineer in Anglo Platinum’s corporate office where he is responsible for drill & blast optimisation, geotechnical projects and predominantly mine to mill integration.

‘Slope Stability Risk Management at Anglo Platinum’s Sandsloot Open Pit’

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum

1 INTRODUCTION

Geology and the detailed understanding of its properties are fundamental to the optimal design and successful operation of any mine. As the knowledge of the geotechnical conditions improves so the risk of unforeseen conditions reduces and therefore safety and productivity can be increased. The paper documents the procedures and developments undertaken to compile a slope stability risk management process at PPRust (Potgietersrust Platinums Ltd.) as illustrated in Figure 1.

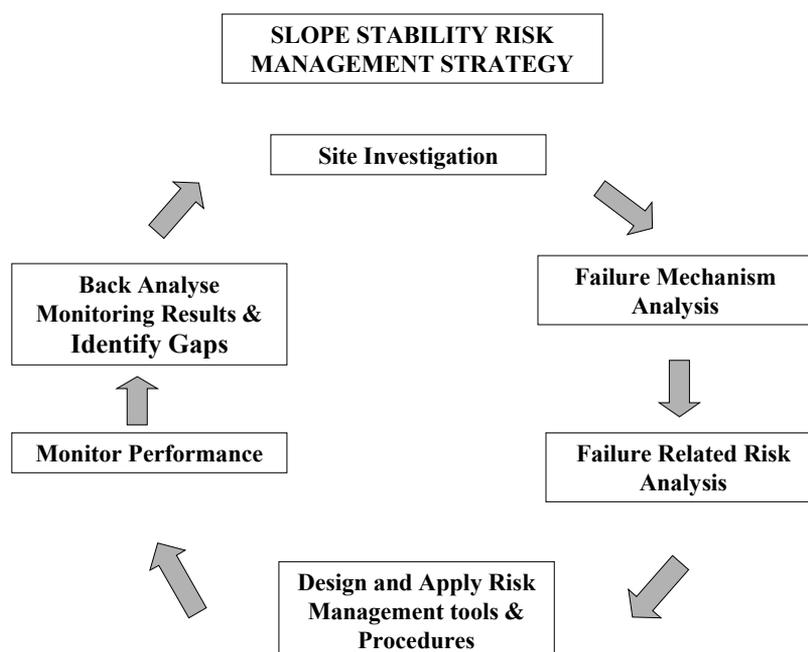


Figure 1. Risk management strategy applied at PPRust.

Extensive fieldwork was conducted to collect geotechnical information, both from exploration boreholes and in-pit mining faces. Over a 5-year period, geotechnical data were collected from +29 km of exploration core and +6,8 km of exposed mining faces. Extensive field and laboratory testing was undertaken in order to define the complete set of geotechnical properties for each rock type in the Sandsloot mining area.

Significant time was dedicated to understanding and back analysing the failure mechanism on the western high wall. This was critical for the appropriate mine design and selection of monitoring tools.

A fault tree is a graphical framework that is used to account for undesirable events and estimate their probabilities of occurrence. This is achieved by illustrating the sequence of events that lead to the undesirable event, including all their possible outcomes and assigning probabilities of occurrence to each event. It is a powerful tool as it highlights high risk areas and the impact of measures to mitigate them. The fault tree quantifies the

'Slope Stability Risk Management at Anglo Platinum's Sandsloot Open Pit'

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum



INSTITUTE OF QUARRYING SOUTHERN AFRICA

Incorporating ASPASA

36TH CONFERENCE & EXHIBITION – 3-5 MARCH 2005



risk and enables management to make informed decisions on the level of risk they are willing to operate at.

Wall control blasting at PPL is stringently applied using pre-splitting, narrow trim blasts, small diameter holes and electronic detonators. The strength of the joints occurring in the western high wall are inadequate to resist even small blast hole pressures and it was therefore important to assess the extent of the joint damage behind the pre-split walls as this would strongly influence the frequency and size of slope failures.

Conventional survey methods, whereby prisms on the crest or face are measured by the Survey department, only provided limited location and time coverage and did not adequately manage the risk presented by these failures. This was due to the small scale of the failures and limited monitoring coverage. The GroundProbe slope stability radar (SSR) was trialled as a possible risk management tool. The SSR has been developed to remotely scan a rock slope and continuously monitor the spatial deformation of the face. Using differential radar interferometry, the system can detect deformation movements of a rough wall with sub-millimetre accuracy, and with high spatial and temporal resolution. The radar currently has a range of 850m and a typical scan will take 8-12 minutes to complete. The aim of the trial period was to determine whether the radar was able to measure and alert operations personnel of brittle rock, slope failures, occurring in the norite hanging wall.

2 MINING OVERVIEW

In 1924, Dr. Hans Merensky located platinum-bearing reef in both the Rustenburg and the Potgietersrus areas. This subsequently resulted in a “platinum rush” and a scramble for mineral prospecting options in both regions. In 1925, over fifty companies had been floated to exploit the deposits of the Bushveld Complex. One of the more prominent was Potgietersrust Platinums Limited (PPL).

Sandsloot open pit was developed in 1992 to extract the platinum-bearing, Platreef ore body, which is hosted within the Northern Limb of the Bushveld Complex, some 250 km north-east of Johannesburg (Figure 2). The current open pit is roughly 1 500 m long, 800 m wide and strikes north. It is the first of six potential open pits to be mined by PPRust, a subsidiary of Anglo Platinum.

Sandsloot is currently the world’s largest open pit exploiting platinum group metals (PGMs). In a single month the mine processes 400,000 tonnes of ore and excavates 50 million tonnes of ex-pit material annually. 25 million tonnes are mined from each of the Sandsloot and Zwartfontein South pits respectively. The Sandsloot open pit is in the process of a fourth cutback, which has a final depth of 200 m below surface while later cutbacks will extend this to a maximum of 320 m. The benches are 15 m in height and mining blocks are usually 100 m x 50 m. The ramps are 35m wide and have a gradient of 10%. The current pit has an economic depth of 320m, after which underground mining may commence.

The Platreef ore body at Sandsloot is tabular in geometry, dips at 45° and is approximately 50 m in width. These properties allow the ore body to be excavated by

‘Slope Stability Risk Management at Anglo Platinum’s Sandsloot Open Pit’

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum



INSTITUTE OF QUARRYING SOUTHERN AFRICA
Incorporating ASPASA
36TH CONFERENCE & EXHIBITION – 3-5 MARCH 2005



open pit mining methods, which is considerably cheaper than conventional underground mining.

3 ENGINEERING GEOLOGY

The Platreef is a pyroxenite ore-body, which is hosted within the northern limb of the basic igneous rocks of the Bushveld Complex. It has an economic strike length of 40 km and contains platinum group elements, copper and nickel concentrations. The Platreef is capped by a sparsely mineralized hanging wall sequence of Main Zone gabbro-norites. This in turn is overlain by Upper Zone sequences of ferrogabbros (Cawthorn, 1996). The mineralization is hosted predominantly within pyroxenite and metamorphosed pyroxenite, locally known as parapyroxenite. The parapyroxenites are conformal with the footwall of the Platreef and are essentially contaminated metamorphosed pyroxenite formed between the cold country rock and the Platreef intrusive phase. The footwall to the Platreef in the Sandsloot open pit is metadolomite known generically as “calc-silicate”. Interaction of the basic magma with the footwall sediments of the Transvaal Supergroup and varying degrees of assimilation has resulted in a unique suite of hybrid rock types. These various rock types provide significant engineering geological challenges.

The Satellite Pit Fault in the south-eastern corner of the pit has downthrown the reef by 50 m while the Sandsloot River on the northern and western pit limits follow another major fault locally called the Sandsloot Fault (Figure 3). According to Friese (2003), these two faults combine to form a major duplex that encloses Sandsloot open pit. Three major joint sets have been identified at Sandsloot, namely JS1 (60/090), JS2 (70/180) and JS3 (70/120). The footwall is stable while the hanging wall contains brittle planar failures, as a result of large-scale fault zones that cross-cut the entire pit (Figure 4). They are ubiquitous and run sub-parallel to the western wall and have an average dip of 60 degrees to the east. Failures, varying in size from 300 t to 30 000 t, have occurred on these fault zones posing the biggest slope stability concern in Sandsloot.

‘Slope Stability Risk Management at Anglo Platinum’s Sandsloot Open Pit’

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum

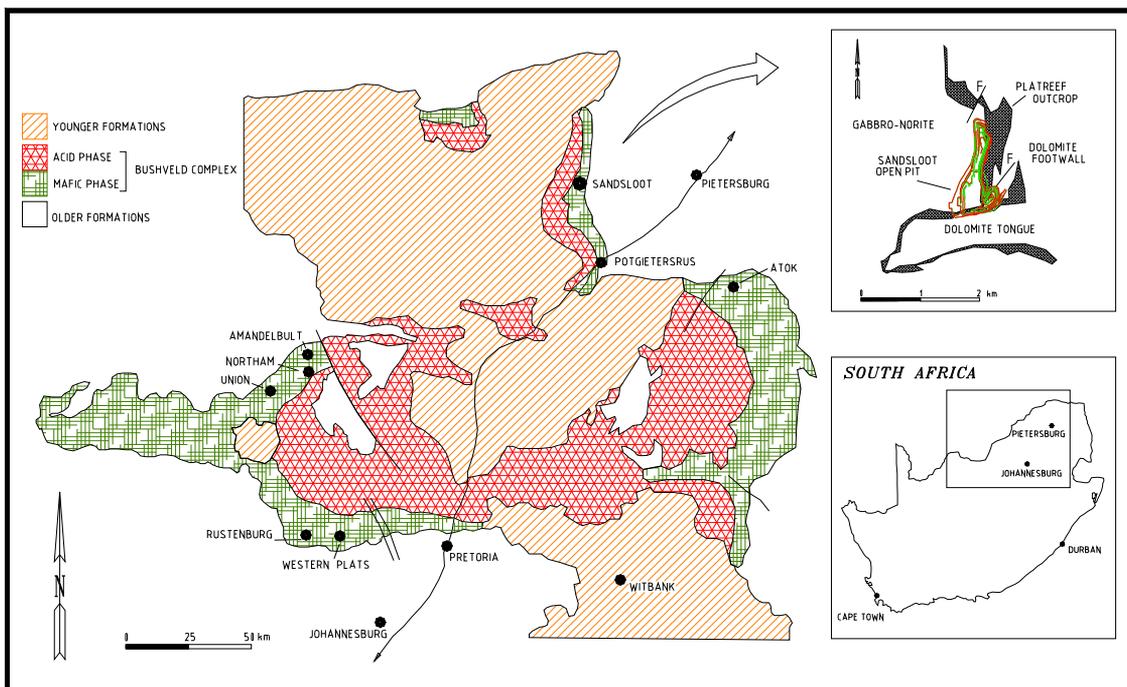


Figure 2. Map of the Bushveld Complex including insets of the mine area and location within South Africa.

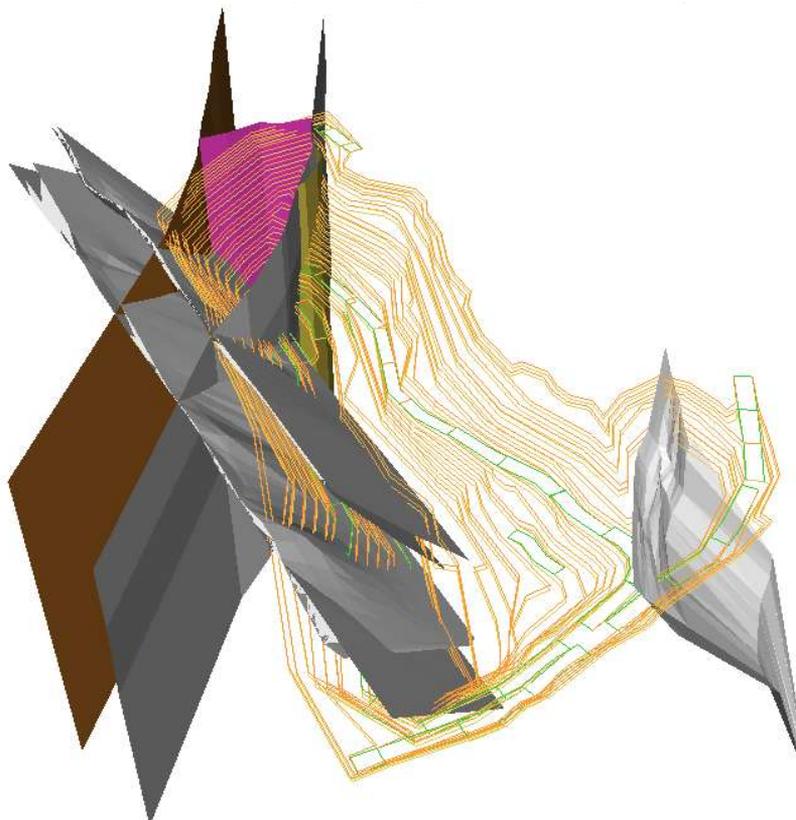


Figure 3. 3D view of the Sandstoot design pit displaying the major structural features.

'Slope Stability Risk Management at Anglo Platinum's Sandstoot Open Pit'

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum



Figure 4. Photograph of fault zones cross-cutting the west wall cutback of the Sandsloot pit.

4 FIELD INVESTIGATION

4.1 Geotechnical Drilling Programme

Structural discontinuities play a major role in the design and maintenance of open pit's and thus their analysis forms the basis for slope stability calculations. Their presence and character have an important influence upon the stability of rock slopes as they affect the mechanical and hydrogeological properties of the rock masses and thus will be the primary cause of any major failures. Hence, the assessment of structural discontinuities forms a critical part of any stability assessment (Friese, 2003). Detailed geotechnical studies at the Sandsloot open pit (Bye & Bell, 2002; Little, 2002) have identified five kinematic failure zones, namely planar, wedge, toppling and circular failure zones, as well as a geotechnical "nose" zone. Each delineated zone represents a geotechnically similar part of the pit, the modes of failure being predominantly structurally controlled (except for circular failures) rather than controlled by rock strength properties. The dominant modes for each geotechnical zone will vary according to the intersection of the pit slope orientation and dominant structural discontinuity orientation.

As exposures become available during mining operations the geotechnical mapping and testing programme is a continuing process thereby determining any changes in the rock mass characteristics. Based on structural mapping the pit has been split up into geotechnical zones. Each zone was studied individually to gain a thorough knowledge of any active or potential stability problems. What is highlighted is the need for comprehensive geotechnical information in order to make informed decisions that affect mining safety and productivity.

'Slope Stability Risk Management at Anglo Platinum's Sandsloot Open Pit'

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum

Orientated diamond drill holes were drilled into the western high wall and the core was logged geotechnically. Particular notice was taken of calcite veins and infilling on joints as the major failures consistently display vein filling on their surfaces. The aim of the drilling programme was to locate the exact positions of the fault zones in the western high wall so that the slope design could be customised. The structural data collected from the boreholes was listed in Excel and plotted on stereonet in DIPS and analysed. This was the best method of identifying the fault zones as the core is very competent and gave very high RQD's of between 95 and 100 per cent (Figure 5). The core confirmed the 0.5 m joint spacing and 10 m width of the critical fault zones seen in the field. Figure 7 displays a geotechnical section of the western high wall with the exploration boreholes and fault intersections.



Figure 5. Photograph of the difficult to identify 'fault zone' occurring in SS02, which was intersected during mining as illustrated in Figure 6.



Figure 6. Small scale failure caused by the fault zone logged in SS02 above. The closed felsite veins were disturbed by blasting and the failure was initiated by heavy rainfall and loading operations.

'Slope Stability Risk Management at Anglo Platinum's Sandsloot Open Pit'

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum

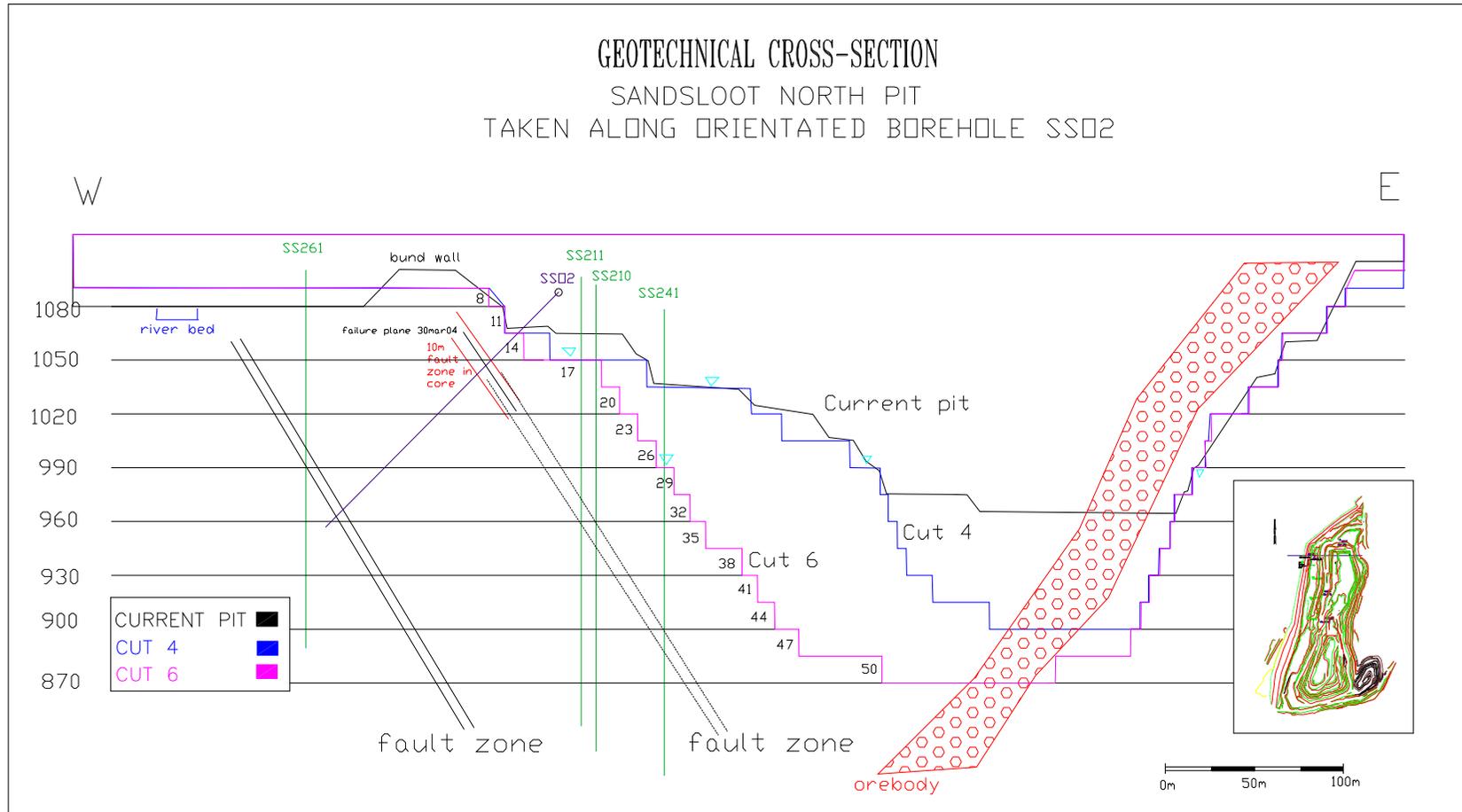


Figure 7. Cross-section through Sandsloot North Pit, taken along orientated borehole SSO2 and including exploration diamond drill holes, all of which were used to delineate the expected fault zones.

'Slope Stability Risk Management at Anglo Platinum's Sandsloot Open Pit'

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum

4.2 Field Mapping

Detailed line mapping was performed throughout Sandsloot pit on accessible faces and combined with the existing geotechnical mapping database. Interpretation of geophysical and remote-sensing data sets was undertaken on a regional scale and diamond drill exploration core was assessed (Friese, 2003). The aim of this work was to delineate the fault zones and the major structures at Sandsloot and create a Structural Interpretation Map of the pit (Figure 9).

Two major fault sets (historically called Joint Set 1 and Joint Set 3) were identified and found to be continuous within the major duplex, bounded by the Sandsloot Fault in the north and the Satellite Pit Fault in the south. The fault sets correlate with the regional structure and the large scale duplex is repeated on a small scale throughout the pit (Figure 8). This is most prevalent on the west wall where imbricate fans occur within the duplexes to form fault zones which sit above the basal normal faults. The fans contain a closely-spaced set of joints which become progressively steeper with increasing distance from the basal fault, resulting in a change in dip of up to forty degrees within a fan. These fault zones are 10 – 80 m wide and 100 - 130 m apart while the duplexes are 70 m in length along dip. This duplex fan phenomenon in conjunction with the large-scale undulations on the joints, cause uncertainty in predicting the location and the probability of failures.

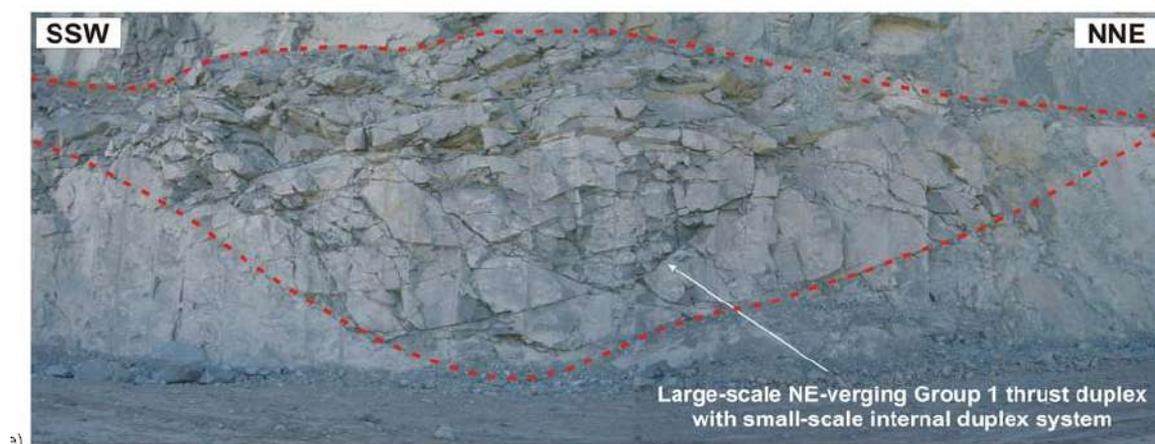


Figure 8. Photograph of the western high wall illustrating the duplex structures (Friese, 2003).

'Slope Stability Risk Management at Anglo Platinum's Sandsloot Open Pit'

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum

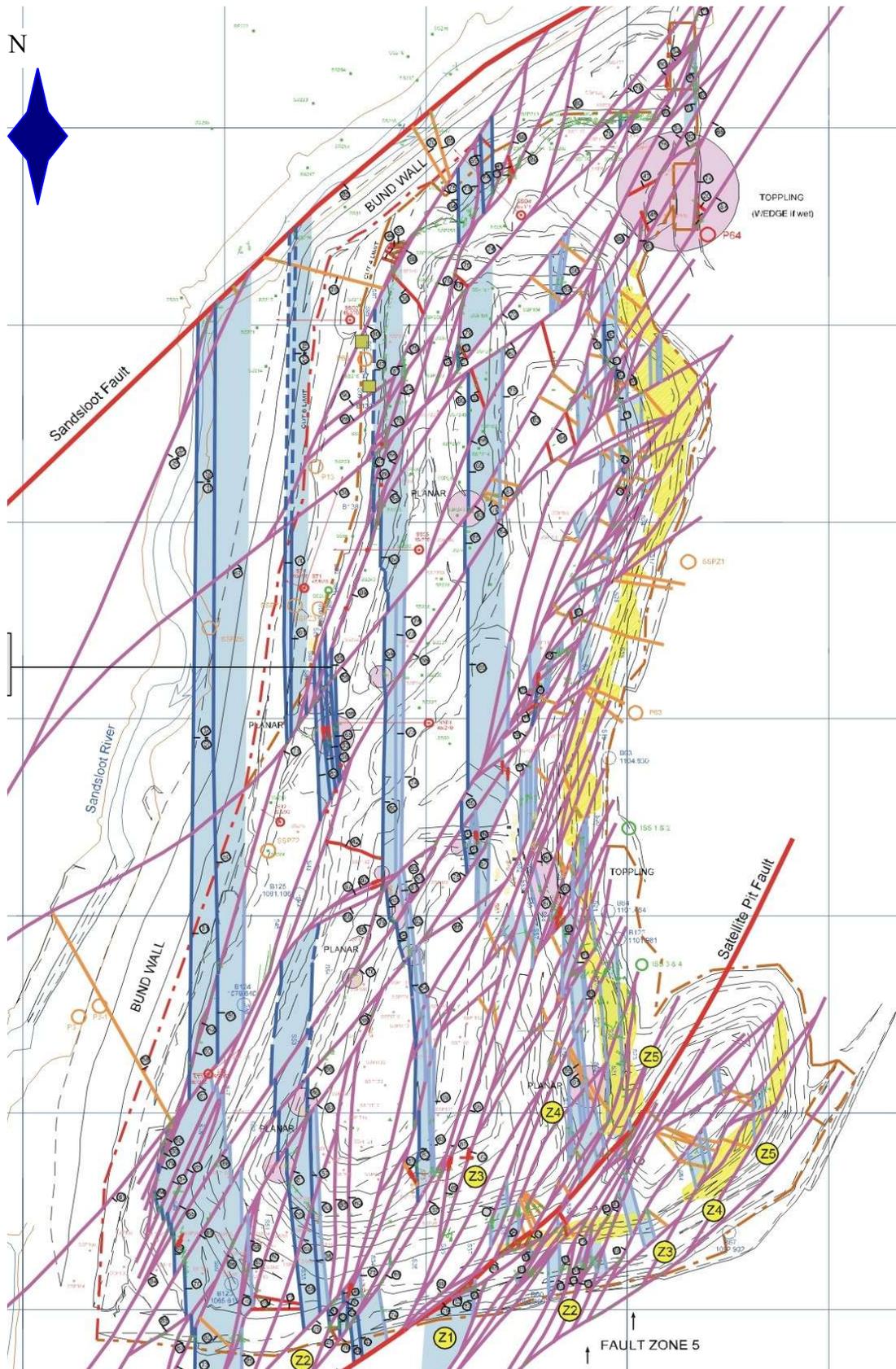


Figure 9. Structural map of Sandsloot open pit indicating the major structural features intersecting the open pit (Friese 2003).

'Slope Stability Risk Management at Anglo Platinum's Sandsloot Open Pit'

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum

4.3 Rock Strength Testing

Laboratory and field tests provide information on the physical properties and mechanical reactions of intact rock. They assist in classifying the rock, thereby allowing relevant engineering design and construction within the rock mass. A detailed rock testing programme (Table 1) was implemented in order to further define the distribution of the rock mass characteristics for not only Sandsloot but also the subsequent open pits that will be mined by PPL. In order to assess the shear strength of the joints within the western high wall a series of natural joint shear box tests were undertaken. The tests yielded a base friction angle of 28° and a residual cohesion of 140 kPa. Joint compressive strength tests yielded a peak strength of 80 MPa. The stability of the Sandsloot slope failures is highly dependant on these strength values and how they deteriorate with repeated dynamic loading from open pit blasting. Additional influences on the stability of the failures are groundwater pressure and lubrication, mining vibrations, weathering and time-dependant gravitational loading.

Table 1. Geotechnical properties of the dominant rock types present at Sandsloot.

	HANGING WALL	ORE ZONE			FOOT WALL
	NORITE	PYROXENITE	PARAPYROXENITE	SERPENTINISED PARAPYROXENITE	CALC-SILICATE
UCS (MPa)	175	160	200	270	140
RQD %	80	65	75	70	55
FF/m	9	13	10	11	16
MRMR	53	48	56	61	42
MRMR CLASS	(III A) Fair	(III B) Fair	(III A) Fair	(II B) Good	(III B) Fair
Unit weight (kN/m ³)	2.9	3.2	3.3	3.2	2.9
Deformation modulus (GPa)	81.0	74	134	108	50

'Slope Stability Risk Management at Anglo Platinum's Sandsloot Open Pit'

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum



INSTITUTE OF QUARRYING SOUTHERN AFRICA
Incorporating ASPASA
36TH CONFERENCE & EXHIBITION – 3-5 MARCH 2005



Poisson's ratio (μ)	0.235	0.187	0.218	0.254	0.291
Tensile strength (MPa)	13	8.0	10.0	13.5	7.0
ϕ_p ($^\circ$)	57-64	40-58	55	-	50
ϕ_b ($^\circ$)	32	29-37	34-36	-	32
JRC	6-10	2-12	8-10	8-12	8-10
JCS (MPa)	87-100	62-100	75	100-150	50

ϕ_p $^\circ$ -Peak friction angle

JRC -Joint roughness coefficient

ϕ_b $^\circ$ -Base friction angle

FF/m -Fracture frequency per

metre

JCS -Joint wall compressive strength

IRS -Intact rock strength (MPa)

RQD -Rock quality designation

MRMR -Mining Rock Mass Rating

'Slope Stability Risk Management at Anglo Platinum's Sandsloot Open Pit'

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum

5 SLOPE DESIGN

5.1 Failure Mechanism Analysis

In basic terms the failure mechanism on the western high wall can be defined as planar failure, whereby a joint bounded block of rock slides down-slope along a planar surface as shown in Figure 10. To satisfy the requirements of a kinematic planar failure the joints must day light in the slope face, they must dip at a steeper angle than the base friction angle, the sliding surface should strike sub-parallel to the slope face and a separate perpendicular joint set must provide release surfaces. All these requirements are satisfied by the structures evident on the western high wall.

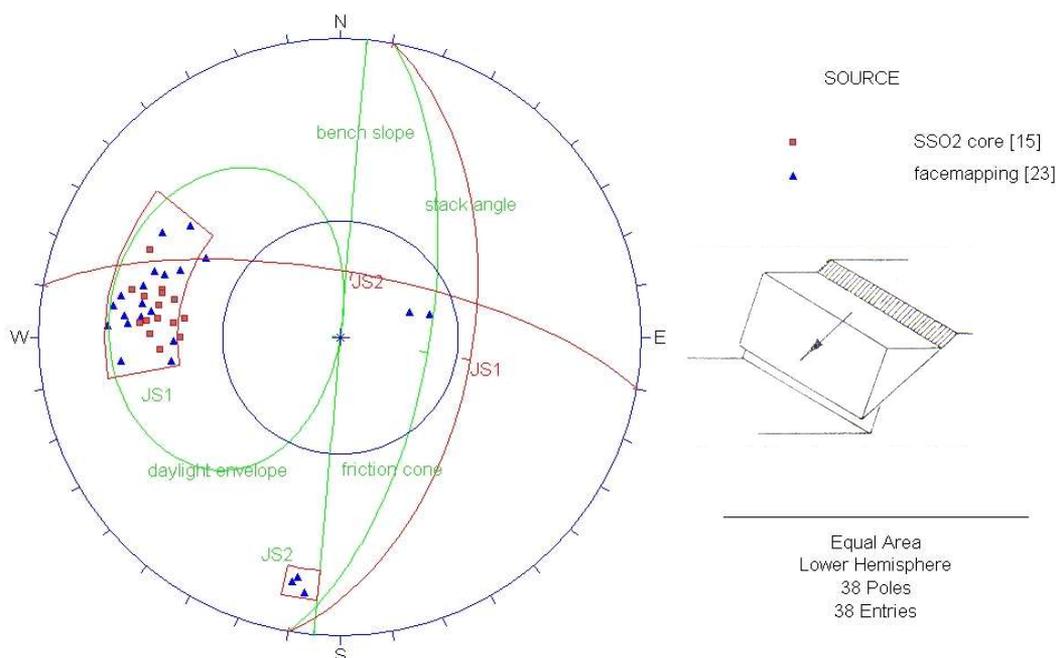


Figure 10. DIPS stereonet of face mapping and core logging measurements from a recent planar failure on the west wall

The failure mechanism evident on the western highwall is however more complex, as the release surfaces provided by JS2 are discontinuous. In order for failure to occur the releasing joints must shear through the 'rock bridge' or competent norite situated between the discontinuous joints. The scale of the planar failures are therefore controlled by the extent of the blast damage and the depth of the rock bridge zone as illustrated in Figure 12.

The primary factors that influence slope failure are dynamic loading from blasting, groundwater pressures and the undercutting of day-lighting joints through the removal of loose material from the toe of the face. Deterioration of joint cohesion over time and general mining vibrations also play a role. Blast energy reduces cohesion on discontinuities and breaks down the rock bridge between joints allowing the formation of a step path failure plane. Water pressure can also initiate failures as rainwater that drains

'Slope Stability Risk Management at Anglo Platinum's Sandsloot Open Pit'

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum

into JS1 faults and joints resulting in a base pressure at the toe of the failure planes. The water also lubricates the clay in-fill material. Undercutting also plays a role in inducing failure. The shovel or back-hoe removes the support and gravity initiates failure. The delay between the undercutting and the failure is dependant on how much rock bridge there is to shear through and how much cohesion there is on the plane.

5.2 Pit Design

Figure 11 illustrates the changes in the final Sandsloot pit design. Prior to the intersection of the major fault structures on the western high wall a single hanging wall ramp was sufficient to ensure reliable pit access. Subsequently a footwall ramp was included to reduce the likelihood of losing access to the pit through a ramp failure. The approach of multiple access ramps was further developed with three access included in the 2004 pit design. Not only does this give operational flexibility for optimising short hauls it also provides security for the long term access to the base of the open pit. It is important to note that the access ramps can be productively used as slope catchment berms so that the overall slope angle is not compromised.

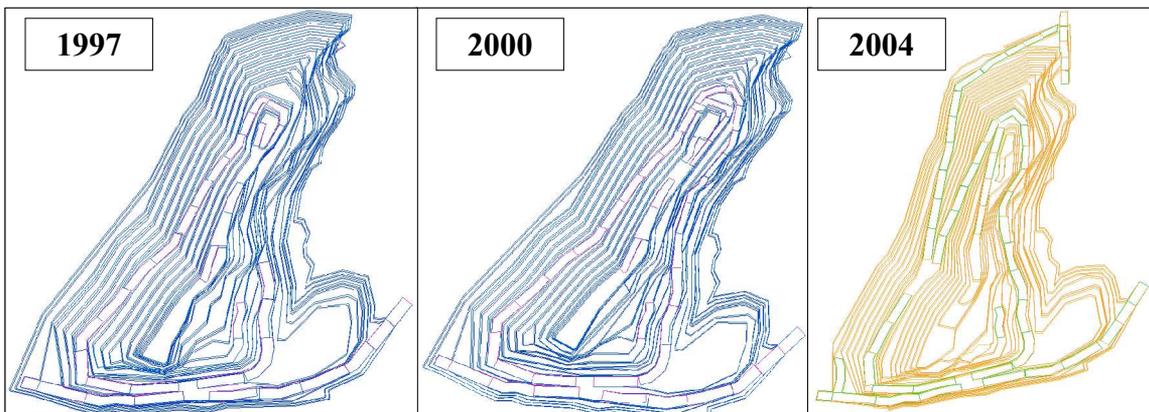


Figure 11. Change in the Sandsloot pit design from 1997 to 2004.



INSTITUTE OF QUARRYING SOUTHERN AFRICA Incorporating ASPASA 36TH CONFERENCE & EXHIBITION – 3-5 MARCH 2005



6 WALL CONTROL BLASTING

The ability to achieve the steep slope configuration at Sandsloot is largely dependant on the quality of the wall control blasting programme. This programme was developed over 7 years and is a well defined blasting process, which reduces to a minimum potential blasting damage to high walls. This essentially consists of pre-splitting, trim blasting and buffer holes all blasted with small diameter holes and timed with Electronic Delay Detonators (EDD's). Additionally, a dedicated 'wall control team' is responsible for the achievement of safe and stable design limits.

Figure 12 illustrates a design section through the Sandsloot western high wall. The typical wall control blast layout is presented with presplit, buffer and trim blast holes of 165mm diameter. As introduced in the rock strength testing section, the impact of blasting energy on the stability of the wall is controlled by the joint and rock strength parameters.

In order to understand what was initiating the slope failures, an analysis of the blast pressures generated by the wall control blasts was undertaken. Three zones are identified in the design section and these should be read in conjunction with the chart presented in Figure 13.

- Zone of rock cracking
 - ~ The blast hole pressure generated by the blast is higher than the UCS of the host rock and cracks are created around the blast hole. This is a confined zone (+/- 2m) immediately adjacent to the blast hole.
- Zone of joint cracking
 - ~ The strength of the joint filling is overcome by the blast hole pressure, resulting in the opening up of the sealed joints (+/- 3m). Depending on the joint strength and the tensile or compressive failure mechanism this can extend to significant distances behind the face.
- Zone of rock bridge
 - ~ Zone of discontinuous rock mass breaks where the tensile strength of the rock and the joints are overcome. This creates a partially fractured rock mass with variable lengths of 'rock bridge' on and between joints. With continual dynamic loading from blasting and mining activities the width of the rock bridge can deteriorate to form a step path failure plane. As seen in Figure 13, this can extend to 20m behind the design limit.

Field observations confirm the graphical analysis results with the failures at Sandsloot occurring in discrete zones where the joint strength is overcome by blasting and the failure is initiated by groundwater pressures or removal of toe support. The failures are typically less than 20,000t and extend to a depth of 10m-20m behind the high wall. It must be noted that if sensitive wall control practices were not being applied, the extent of the blast damage would be greater and this would result in larger and more frequent failures. In turn this would result in unmanageable risk levels.

'Slope Stability Risk Management at Anglo Platinum's Sandsloot Open Pit'

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum

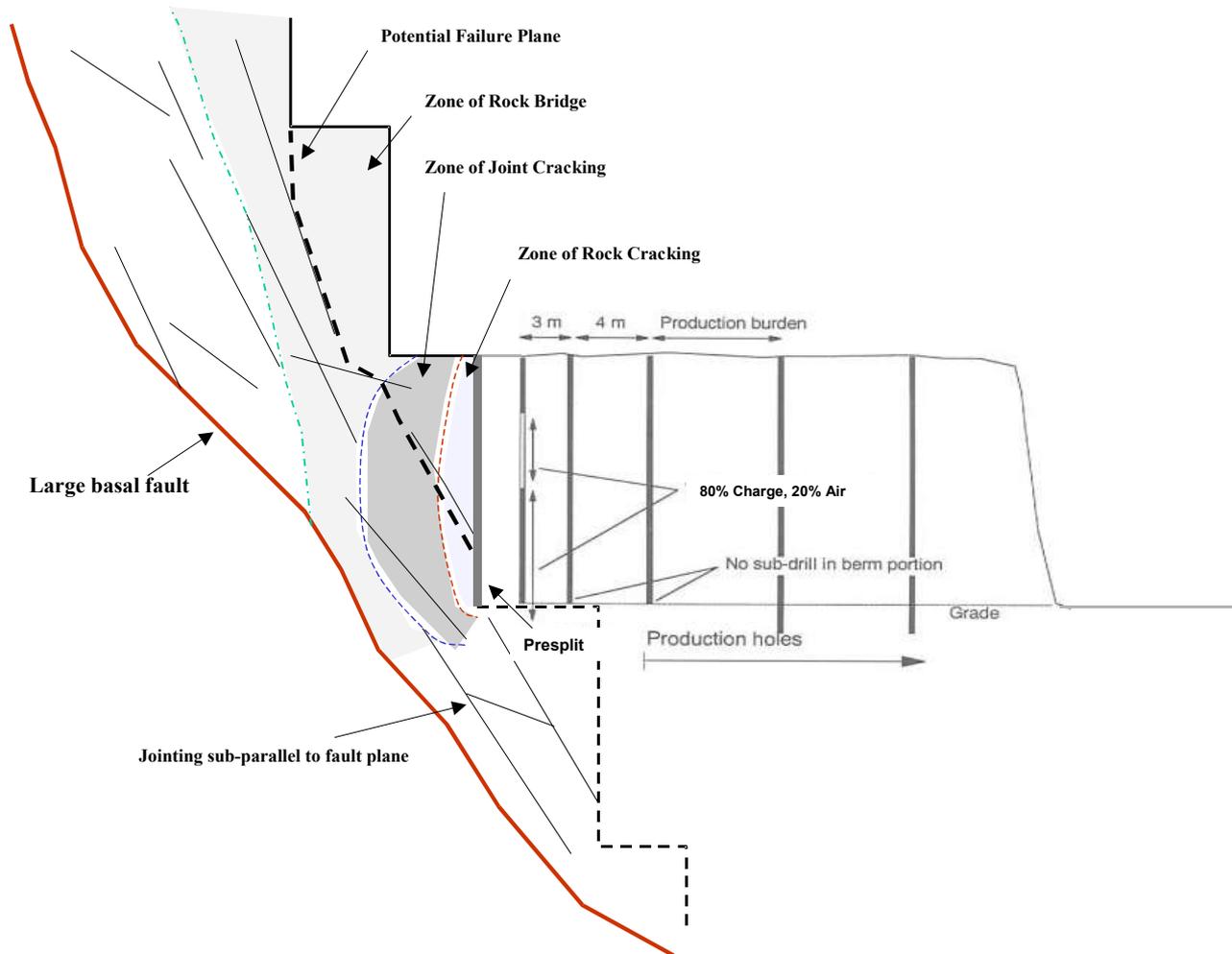


Figure 12 Illustrates the impact of blasting on the competence of a highwall.

WALL CONTROL BLAST
Pressure vs Distance

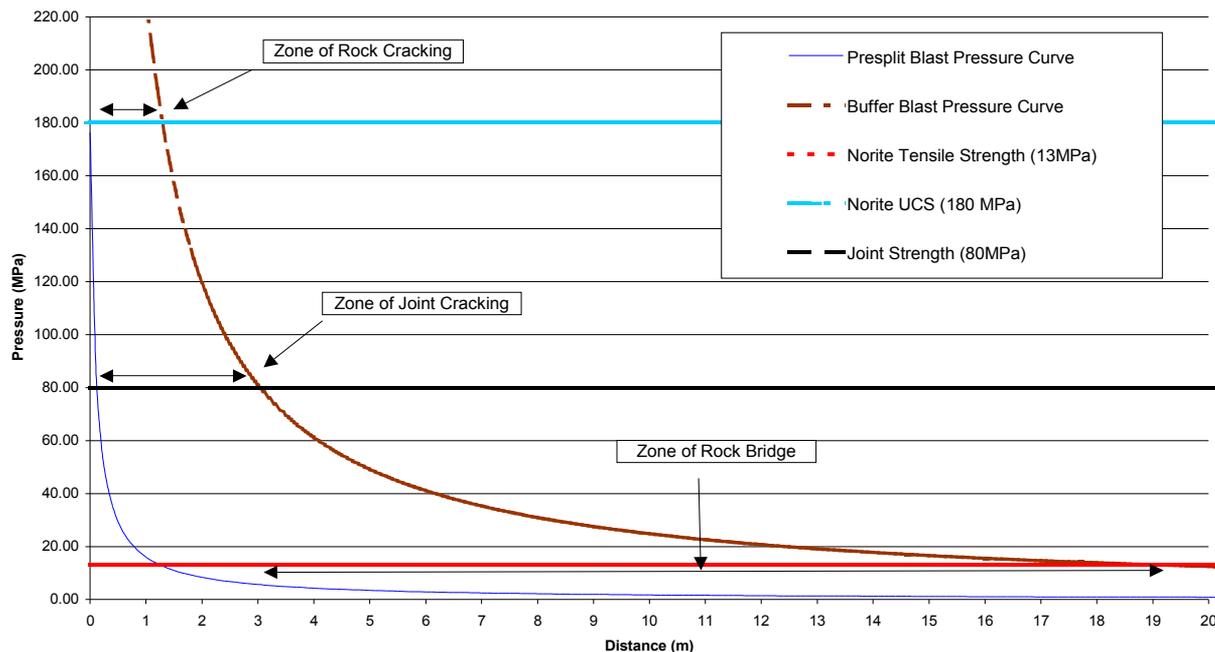


Figure 13 Assessment of blast damage zones from a wall control blast. The chart illustrates the drop of blast pressure from a blast hole with distance and to what extent fracturing of different rock materials occurs.

'Slope Stability Risk Management at Anglo Platinum's Sandsloot Open Pit'

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum



INSTITUTE OF QUARRYING SOUTHERN AFRICA

Incorporating ASPASA

36TH CONFERENCE & EXHIBITION – 3-5 MARCH 2005



7 FAULT TREE ANALYSIS

7.1 Introduction

A fault tree is a graphical framework that is used to account for undesirable events (e.g. fatality, damage to equipment, economic loss) and estimate their probabilities of occurrence (Anon., 1999). The framework illustrates the sequence of events that lead to the undesirable event, including all their possible outcomes and assign probabilities of occurrence to each event. 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.

7.2 Sandsloot Framework

At Sandsloot, a fault tree analysis was done in order to quantify the risks posed by the failures on the western high wall. The fault trees were designed to calculate the probability of a fatality, which was then compared to the international acceptable level of risk (Figure 14). Failure on a bench, stack and overall slope was used as the root cause/event and the design probabilities of failure assigned. The design probabilities, calculated from Slide (RocScience, 2003) and kinematic failure analysis, were adjusted to take into account operational conditions, such as wet slopes and the impact of blasting. Risk mitigation measures the effectiveness of monitoring, personnel awareness and evacuation in response to a failure was incorporated in the fault tree and personnel exposure to the failure incorporated to produce an overall probability of fatality.

7.3 Results

Various fault tree scenarios were run to determine the effect that improved monitoring techniques as well as improved awareness, 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. Bench, stack and overall slopes for the current Cut 4 as well as the final Cut 6 designs were analysed. Results from the analysis show that failure on a bench and especially stack scale are the highest risk in Sandsloot. The slope stability radar significantly reduced the safety risk thereby allowing operations to continue within internationally accepted safety standards (Figure 15). Other improvements such as training, slope design configuration, operations work procedures, awareness, evacuation drills and slope dewatering also have a large effect on reducing risk and are an essential part of the risk management programme.

'Slope Stability Risk Management at Anglo Platinum's Sandsloot Open Pit'

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum

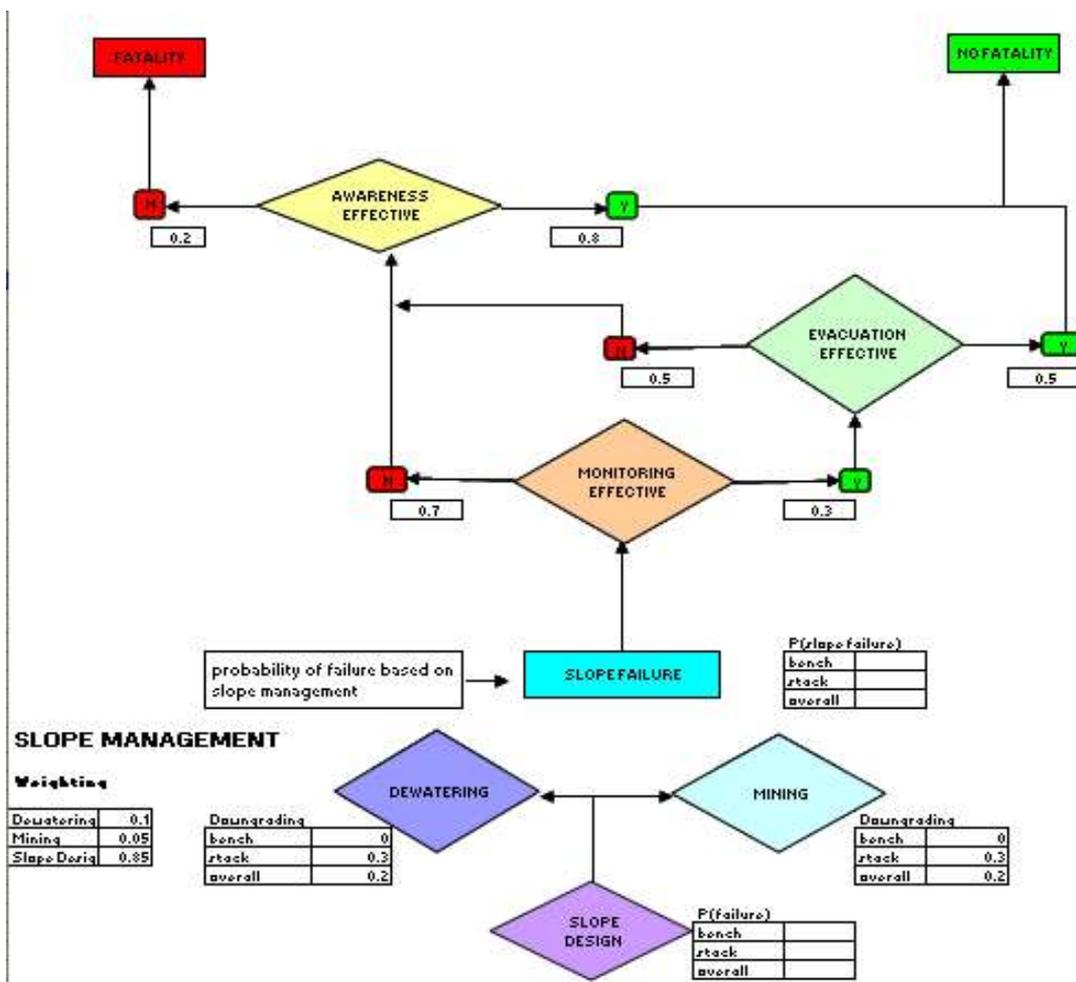


Figure 14. Fault tree designed for Sandsloot
 Probabilities of fatality at Sandsloot

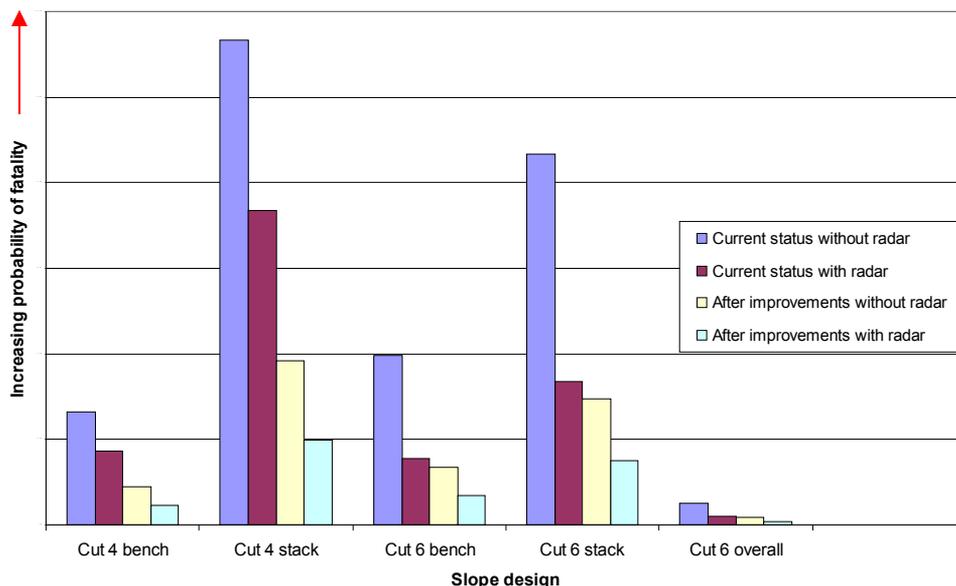


Figure 15. Risks obtained from the fault tree analysis

'Slope Stability Risk Management at Anglo Platinum's Sandsloot Open Pit'

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum



INSTITUTE OF QUARRYING SOUTHERN AFRICA

Incorporating ASPASA

36TH CONFERENCE & EXHIBITION – 3-5 MARCH 2005



8 SLOPE MONITORING STRATEGY

As discussed in the previous sections a great deal of time was spent on understanding the failure mechanisms at Sandsloot, what initiates failure and the resultant risk levels. This information enabled the appropriate selection of slope monitoring or risk management tools.

The slope monitoring tools were selected to provide early warning in a congested pit containing brittle slope failures. Owing to the short time to failure the monitoring would need to provide as near to real time information as possible. The equipment would also need to be mobile and have good resolution to detect the small scale failures. The following strategy was selected:

- Long term
 - ~ The ISSI seismic monitoring system was installed to detect vibrations caused by movement and cracking on major fault planes. The frequency of vibrations are assessed on a monthly basis. The system is suited to detecting large scale failures and is still under trial.
- Medium term
 - ~ Conventional survey monitoring of prisms installed on a 50m x 45m grid. The monitoring is done by the GeoMoS system, which consists of automatic total stations positioned on the crest of both the eastern and the western high walls at Sandsloot. Each one covers half of the pit walls on a 24-hour basis and is configured to measure all the prisms every 3 hours. A sms is sent to the relevant staff when excessive movement, determined by geotechnical staff, occurs. A computer dedicated to GeoMoS is set up in the Survey office where the data can be viewed and plotted on displacement, velocity and vector graphs.
- Short term
 - ~ Identified problem areas are equipped with crack meters and regular field inspections highlight the deterioration of these areas.
 - ~ Daily visual inspection of all active mining faces by geotechnical and operations staff, which identifies areas of concern and poor ground conditions.
- Real time
 - ~ A mobile, global monitoring system was required to detect and provide warning of the small-scale brittle failures. The GroundProbe slope stability radar was ideally suited to this task.

'Slope Stability Risk Management at Anglo Platinum's Sandsloot Open Pit'

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

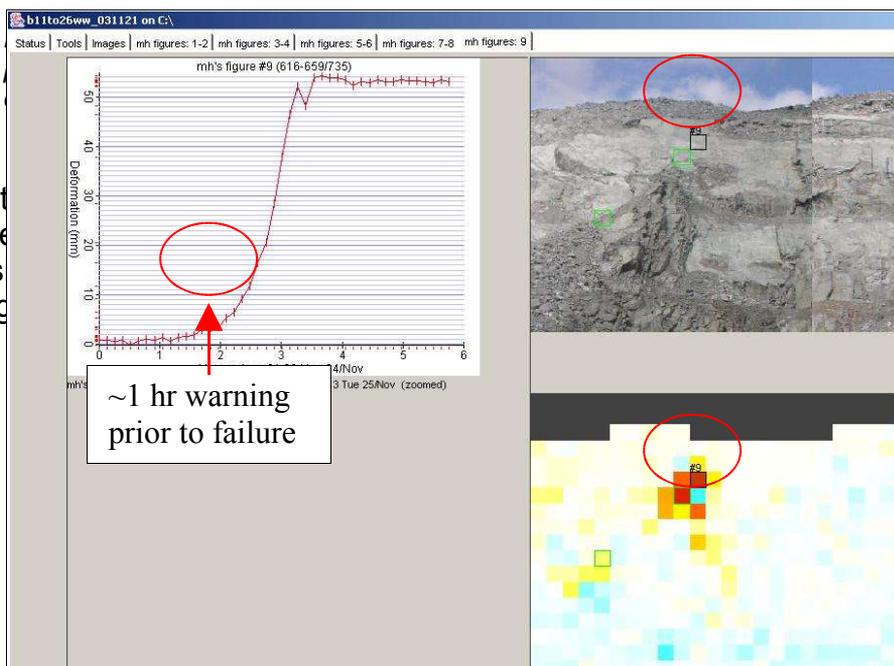
Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum

9 GROUNDPROBE SLOPE STABILITY RADAR

The GroundProbe slope stability radar (SSR) uses differential interferometry to measure sub-millimetre movements on a rock face. The SSR has a range of 50 - 850 m and an accuracy of 0.2 mm. It operates in all weather conditions, 24 hours a day and it scans the chosen area of the high wall roughly every ten minutes. A 2-dimensional deformation image is produced and any number of deformation plots can be drawn at user-specified locations in the scanned area. It has customisable alarm settings and masking options in a user-friendly software programme. GroundProbe began leasing their first SSR unit in 2002 in Australia where they currently have 7 operational units at various hard rock mines. The GroundProbe SSR was brought to Sandsloot on an initial 2 month contract. The aim of the trial period was to determine whether the radar was able to measure and alert operations personnel of the brittle slope failures in the pit.

The first international SSR unit arrived on site at PPL in November 2003 and was trialled for the 2 months. During the trial at PPL, the SSR recorded a minor slope failure and triggered a red alarm, which enabled early warning to be given to pit personnel. As no work was underway in the vicinity, production was not affected but the failure proved that the radar was the appropriate monitoring tool for Sandsloot. The <300 t failure showed up on the SSR plots as an exponential curve of 54 mm movement over 120 minutes (Figure 16). This indicates that rapid response to slope failures at PPL is required in order to keep personnel safe and to minimise damage to equipment.

As the t
now bec
giving s
showing



d and the SSR has
the 28 March 2004
r 80 minutes, again



Figure 17. Photograph taken on 31 March 2004 of the radar and the failed block that was monitored.

Figure 18. SSR screen dump with deformation-over-time plot, photograph and deformation image of the 20 000t brittle failure in Sandsloot open pit on 20 March 2004.

It is important to note that the SSR measures movement in the direction of the radar i.e. relative movement and not absolute movement, and provides a 2-D picture of the slope. The actual movement seen on the face was 5 m downslope. Work is currently being done on site to relate the two measurements while GroundProbe aims to introduce 3-D deformation plots within 12 months.

10 FUTURE MONITORING TECHNOLOGY

With the geotechnical challenges encountered on the western wall in Sandsloot open pit, a global early warning device like the SSR is essential to the efficient running of the mine. The SSR is however, not the only global monitoring system on the market. An Italian company, LiSALab, has developed a ground-based synthetic aperture radar (GB-SAR), which provides 3-D deformation images of absolute movement at a range of 1.5 km. These radars have been in use for the past 6 years in landslide and structural monitoring and a unit is currently being tested at a small open pit in Italy. The area monitored by the GB-SAR can be displayed as a digital elevation model (DEM) and deformation / time graphs can be plotted. A Swiss company, RiegI, have also developed a laser system, which they claim can perform automated 3-D slope monitoring to a high level of accuracy, but it has yet to be tested in South Africa.

'Slope Stability Risk Management at Anglo Platinum's Sandsloot Open Pit'

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum



INSTITUTE OF QUARRYING SOUTHERN AFRICA

Incorporating ASPASA

36TH CONFERENCE & EXHIBITION – 3-5 MARCH 2005



The GroundProbe SSR in conjunction with the conventional prism monitoring, visual face inspections, piezometers and water level monitoring, extensometers as well as the ISSI seismic system, which measures micro-seismic movement within the slope, provide a comprehensive slope monitoring programme at Sandsloot. Extending the ISSI system and trialling the LiSALab and Riegl systems are the next steps in ensuring the personnel at PPL are provided with the best possible early warning technology at reasonable prices.

SiroVision is a software package used for mapping by digital photogrammetry. It enables mapping to be done rapidly and from a safe distance to unstable high walls. One can identify joints, measure their dip and dip direction and plot them in 3-dimensional space on pit plans and slope configurations. It was trialled at Sandsloot and found to be an ideal mapping tool for the ubiquitous joints on the western high wall.

11 CONCLUSION

The purpose of this paper was to document through a proven case study the knowledge collected from the application of the slope stability risk management strategy. The described procedures will hopefully assist greenfield and existing operations with selecting the appropriate slope management strategy.

Extensive fieldwork was conducted to collect geotechnical information and the detailed understanding was fundamental to the optimal design process undertaken. Significant time was dedicated to understanding and back analysing the failure mechanism on the western high wall. This was critical for the appropriate mine design and selection of monitoring tools

The use of probability fault trees enabled the selection of the most appropriate mitigating risk measures and comparison with internationally accepted risk levels. The fault tree quantifies the risk and enables management to make informed decisions on the level of risk they are willing to operate at.

The impact of the blast pressures on the joint filling was analysed to determine the depths of damage and therefore expected failure volumes. Blast hole pressure versus distance curves were analysed in order to assist with understanding the failure mechanism. Based on the potential blast damage zones and the intersection of the major west wall structures, areas of potential failure can be identified.

As part of the risk management strategy the monitoring systems at Sandsloot were selected based on long, medium, short and real time monitoring requirements. The application of the GroundProbe SSR at PPL has proven very successful and the initial trial period has been extended for the duration of 2004. With the geotechnical challenges presented by the western high wall in both open pits, a global, early warning device like the SSR is a powerful operational tool for the safe and efficient operation of the mine.

'Slope Stability Risk Management at Anglo Platinum's Sandsloot Open Pit'

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum



INSTITUTE OF QUARRYING SOUTHERN AFRICA

Incorporating ASPASA

36TH CONFERENCE & EXHIBITION – 3-5 MARCH 2005



The paper documents the procedures used to collect data, define the dominant failure mechanism, develop appropriate designs, assess the design risks using probability fault trees and finally the implementation of a slope monitoring and wall control blasting strategy to manage the failure risk. Figure 1.1 illustrates the risk management process followed at PPL. The process has been successfully applied with the appropriate level of monitoring and design, tailored to Sandsloot's specific challenges.

12 REFERENCES

1. Cawthorn, R.G. 1996. *Layered Intrusions*. Elsevier Science, London.
2. Friese, A. 2003. The structural geology of the PPL concession area, with implications for the tectonic-magmatic evolution of the northern limb of the Bushveld Igneous Complex. SRK Report No. 186322/2 October 2003.
3. Bye, A. R. and Bell, F. G. 2001. Stability assessment and slope design at Sandsloot open pit, South Africa. *International Journal of Rock Mechanics and Mining Sciences*. Pergamon, 38; 449-466.
4. Little, M.J. 2002. Development of a major feature plan and ramp stability analysis at Sandsloot open pit, Limpopo Province, South Africa. *B.Sc. Honours dissertation (unpubl.)*, University of Cape Town, Cape Town, South Africa, 50 pp.
5. RocScience Inc. 2003. *Geomechanics software and research*. 31 Balsam Ave., Toronto, Ontario, Canada, M4E 3B5.
6. Anonymous. 1999. An overview of probabilistic analysis for geotechnical engineering problems. *Risk based analysis in geotechnical engineering for support of planning studies*. US Army Core of Engineers.



'Slope Stability Risk Management at Anglo Platinum's Sandsloot Open Pit'

Author/Speaker: Alan Bye - Geotechnical Engineer, Anglo Platinum – Mining & Geological Services

Co-Authors: Megan Little – Rock Engineer, Desmond Mossop – Manager, Rock Engineering – PPRust, Anglo Platinum