Rockpass overview and risk assessment within the AngloGold Ashanti SA region

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Synopsis

Ongoing rockpass problems on mines within the South African region, prompted AngloGold Ashanti to embark on a risk assessment of major rockpasses. This commenced with the collection of relevant data to identify gaps in the available knowledge and identify existing problems. This was followed by an assessment of rockpass layouts to determine existing and potential interactions with other excavations.

An initial risk assessment has been completed and the rockpasses have been ranked in terms of their risk profile. The lack of geological data and an easy and reliable method of surveying rockpasses have been identified as problem areas. Shortcoming is terms of rockpass management procedures have also been identified. Further work is required to quantify the risk in terms of probability of occurrence and consequences.

Introduction

Problems in the main rockpasses on mines within AngloGold Ashanti SA Region have been experienced for many years. The following are brief descriptions of a few of the cases.

President Steyn 4 Shaft

In 1985 two workers were killed due to the failure of a shaft rockpass box front during the commissioning of the sub-shaft. On investigation it was found that this bored rockpass had no Y-leg—the ore impact was directly onto the box front. No professional civil engineering design had been carried out, nor was there any quality assurance on the construction. On investigation it was found that, generally, all of the new rockpasses had similar problems and, further, that incorrect design loads had been used for the box front control chutes and the 'design' of the concrete work. In other words, a very unprofessional approach had been applied to this critical work due to little understanding of the issues. In addition, no maintenance plan had been put in place for the rockpasses.

A remedial plan of action was put in place, which included:

Mining of Y-legs where applicable
Redesign of all box fronts to agreed standards
Reconstruction of all box fronts and control chutes with proper QA/QC.

This programme took about two years to complete, and was costly and very onerous, especially since the shaft was in a fast track build-up phase. This would not have occurred, had the job been done correctly the first time.

Matjhabeng Mine

In 1998 a box controller was killed at an inter-level rockpass. A wall had been constructed where the pass intersected a cubby. A blockage had occurred in the pass somewhere above the cubby and when it broke away, it resulted in a concussion that caused the wall to be blown out, killing the worker. Again no proper design or construction had been carried out. The wall was redesigned with a pressure relief vent. If this had been done in the first place it would have saved a life.

Savuka Mine

In 1998 a seismic event with a magnitude of 3.3 occurred in the shaft pillar area, destroying the middling between the reef rockpass and the tertiary vertical shaft over a distance of 70 m at a depth of about 3000 m. The shaft was out of commission for some five months while intensive support was installed in the shaft lining and a steel tower was installed in the shaft to cater for movement. The effect of the seismic event was a surprise since nobody was aware that the rockpass had significantly self-mined, or if they did, they did not fully understand the consequences.

Great Noligwa Mine

Over the years the shaft pillar area within the working levels has been drilled like 'Swiss

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cheese' as more and more rockpass legs failed and new ones were required. Why did the legs fail? Only one reason - they self-mined to such an extent that they either became too large (~100m in some cases) or that the very large boulders that blocked the chutes became too difficult to handle. The reasons are simply explained:

- The shaft was sited in a very complex geological area
- The alignment of the rockpasses was poorly done with regard to strata intersections
- Lack of maintenance plans.

The latter two are planning and design faults. New and appropriate maintenance plans were put in place. The ultimate solution for this mine is to relocate the rockpasses outside the shaft pillar at great cost and effort.

The significant production losses that resulted from the Savuka case described above prompted AngloGold Ashanti to embark on a comprehensive programme to identify potential disaster conditions or scenarios. An initial assessment for all operations was conducted by Handley (1990) who recommended that further detailed analysis was required per mine and that comprehensive files containing all relevant information were required per rockpass system.

This paper outlines the assessments conducted on the major rockpasses in an attempt to gather all relevant information and manage the risk. The main rockpasses are defined as those inter-level rockpasses situated within the various shaft pillars. The purpose of this work was as follows:

- Identify areas of damage or deformation in the main rockpass system that may be symptomatic of 'disaster conditions'
- Collect and collate all available knowledge about the major rockpasses and identify knowledge gaps
- Develop and maintain a system that ensures both awareness of potential disaster scenarios and that information on such scenarios flows correctly to ensure timely decision making.

Rockpass overview

The rockpass study considered the major rockpasses situated within the shaft pillar area. One hundred and seventy rockpass legs were considered in this study. The following is an overview of the rockpasses:

- The majority of the older passes (40%) at Savuka and Tau Tona were developed conventionally by drill and blast methods. Typical dimensions were 2 m by 2 m
- The remaining newer rockpasses were bored with diameters generally of 2 m and 2.4 m. In some cases, larger diameter (8 m) silos were also bored
- Lengths vary between 20 m and 170 m, although the majority are in the 80 m to 110 m range
- Generally, the inclination varies between 60 degrees and vertical
- Only a small proportion of main rockpasses was initially lined
- These rockpasses have been developed in different rock types ranging from various quartzites to lavas
- Several are intersected or influenced by geological structures
- The range in depth varies between 900 m and 3 400 m below surface with the bulk in the 2 000 m to 3 000 m range

Overview of rockpass problems

Risk sources

There are two sources of risk associated with damage to rockpasses (Dunn, 2004):

- Production delays and losses
- Damage to adjacent excavations or infrastructure that can result in production delays, rehabilitation costs and injuries to personnel.

Delays to production can result from blockages due to large rocks or down time for rehabilitation of rockpasses that have scaled excessively.

In terms of damage to other excavations, this could be the result of the following:

- Interaction between rockpasses, possibly resulting in increased dilution and ore accounting difficulties
- Interaction with horizontal excavations, resulting in stability problems, such as undermining of tipping areas
- Interaction with vertical excavations such as shafts, creating stability problems.

Factors influencing rockpass damage

Damage to rockpasses can be due to a number of factors and is often due to a combination of factors. Several of the main factors are outlined below.

Geology

The presence of geological discontinuities (bedding, joints, faults, dykes and veins) and a low intact rock strength can result in a poor quality or low strength rock mass. This would be more prone to damage, especially when associated with unfavourable stress conditions.

Stress

This includes high absolute stress, stress changes and stress orientation. High horizontal stresses in a particular direction could exacerbate the potential for scaling or dog-earing.

Design and layout

This includes factors such as the size, length, inclination and spacing. These factors must be considered relative to geology, stress field and other excavations.

Excavation method

Whether a rockpass was bored or blasted, will impact on the type and extent of deformation around a rockpass.

Erosion and attrition

This will depend on the type of rock (hardness, size and shape) passing through the rockpass, volumes, impacts and nature of the rock flow.

Assessment process and methodology

The following process has been followed (Dunn, 2004):

- Data collection via comprehensive questionnaires

Audit of existing rockpass management systems and action plans
Rockpass potential risk assessment and ranking
Monitoring of action plans and regular progress reports

Data collection

Initial discussions indicated that very little formal information was available about the approximately 170 main rockpass legs within the SA Region. A comprehensive questionnaire (Table I) was developed (Laas, 1999) and completed by each of the mines for each main rockpass segment.

Audits

Following the questionnaires, meetings with the rock engineering managers and engineering managers on each of the mines were conducted. The purpose of these meeting was to review the following aspects (Dunn, 2004):

Status of monitoring programmes
Capturing of rockpass dimensions and profile in 3-dimensional graphics on the Cadsmine (computer assisted design) planning system
Geological sections of rockpasses, indicating intersections with significant geology
Rockpass management procedures in terms of recording and reviewing rockpass problems
Knowledge of problem areas
Rehabilitation action plans and schedules
Rockpass documentation (reports, plans and sections).

Rockpass risk potential assessment and ranking

A system was developed in an attempt to qualitatively assess rockpass risk potential by relating interaction risk to damage status (Naismith, 2002; Dunn, 2004). The assessment methodology is shown in Figure 1. This system focuses on the layout and can be used to rank different rockpass segments. The following factors are considered:

Damage status
Information reliability
Interaction status.

Information reliability

The information available on the damage varied between different rockpasses in terms of completeness, quality and age. Lack of information was considered to have a negative impact and to increase the risk. An attempt was made to allocate a confidence level to the information available using Table II.

Interaction status

This is based on several empirical layout ‘rules of thumb’ in terms of the spacing of excavations relative to each other (Table II). Actions for different situations are also outlined.

Table I
AngloGold Ashanti main rockpass risk assessment questionnaire

Questions relating to shaft main rockpass segment	Answer	Comments	Rating
Has a rockpass stability RE design report with specific recommendations been issued for this excavation?			
Have the design recommendations been implemented?			
Is an alternative rockpass available should this one refuse?			
Must this rockpass be protected for the life of the shaft?			
Was this rockpass excavated by blasting or boring?			
Rockpass cross-sectional dimensions and orientations—original?			
Rockpass cross-sectional dimensions and orientations—current?			
Is the shaft pillar intact or mined out?			
Is the shaft pillar surrounded by mined-out area?			
What are the rockpass start- and end-elevations?			
Elevation of the reef-rockpass intersection(s)?			
Average strata dip, channel width?			
Do significant geological structures intersect the rockpass?			
Do, or could any other excavations interact and potentially destabilize any part of the rockpass?			
Does a seismic monitoring system include the rockpass area?			
Is a sufficient rockpass monitoring system (other than seismic) operational and used?			
Does a recording and communication system ensure all stake are informed of any blockage, damage, and repairs to this main rockpass?			
Has the rockpass been affected by rockmass deformations, movements, seismicity or hang-ups?			
Are the rock flow characteristics known?			
Have you ever had to repair this rockpass by blasting and/or support?			
Are the repairs to the rockpass continuous or historical?			
What support has been installed in this rockpass, why and when?			
Are any other infrastructure excavations vulnerable to or being damaged by this rockpass?			
Rating main rockpass stability in shaft pillar conditions.*			

*Rating scheme: No problem = 0, Slight problem= 1, Moderate problem = 3, Serious problem = 10

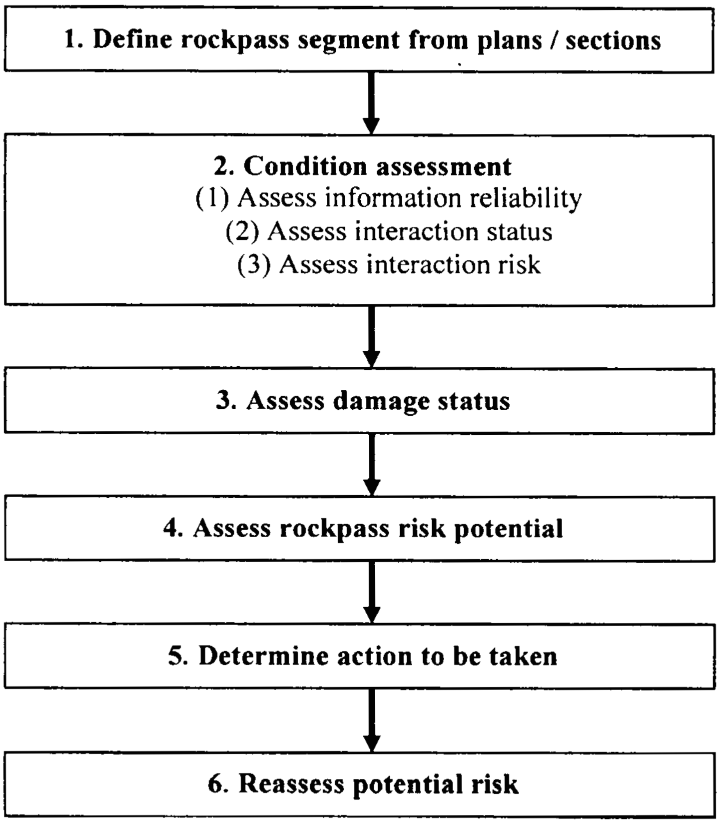

Figure 1—Outline of rockpass risk potential assessment process (Naismith, 2002)

Table II

Information reliability (Naismith, 2002)

Rating	Confidence with regard to status (dimensions/scaling rate/filling)	Comments
1	>80%	Recent physical measurements
2	60–80%	Recent observations but no physical measurements
3	40–60%	Conditions deduced by operating conditions (damage/hang-ups)
4	<40%	No information

Damage status

Table IV is used to qualitatively rate the damage status per rockpass leg. The scale is based on delays to production. This could be related to a monetary loss.

Assessing rockpass risk potential

The information is entered into a table (Table V) and the interaction risk is determined by multiplying the information reliability by the interaction status. Thereafter the interaction risk and the damage status are used to determine the potential risk using the matrix in Table VI.

Actions plans and monitoring progress

Following the audits and an initial review of the available

Table III

Interaction status (Naismith, 2002)

Rating	Criteria	Action
1	No interaction: minimum septum between excavations > 3x combined dimension. May have erosion damage	Monitor periodically to establish wear rates
2	Potential interaction: minimum septum between excavations <3x combined dimension	Monitor regularly to establish wear rates
3	Imminent interaction: minimum septum between excavations <1x combined dimension Septum is likely to be at elevated stress and undergoing deformation Scaling is expected but not yet observed	Monitor regularly Schedule remedial actions
4	Actual interaction: minimum septum between excavations <1x combined dimension Septum at elevated stress. Scaling and deformation observed. Possible seismic activity	Immediate remedial action
5	Holing: excavations have broken into one another	Stop and repair or relocate

Table IV

Damage status (Naismith, 2002)

Rating	Criteria
1	No significant damage: no production delays. May have minor abrasion and scaling
2	Minor abrasion and scaling: no significant delays to production (dealing with hang-ups or large rocks in boxes) Delays <1% of operational time (< 4 hours/month). Maximum dimension <2x original dimension
3	Significant abrasion and scaling: noticeable delays to production of up to 5% of operational time (±20 hours/month) Maximum dimension >2x original dimension
4	Severely damaged: delays to production such that one or more excavations are decommissioned for remedial work Maximum dimension >5x original dimension
5	Very severely damaged: visible and ongoing damage to adjacent excavations in which people are exposed Potential to cause very long production delays (several weeks) or cause injury to people

Table V

Rockpass potential risk assessment (Naismith, 2002)

Rockpass segment	(A) Information reliability	(B) Interaction status	(C) Interaction risk (A*B)	(D) Damage status	(E) Risk potential	Comments

Table VI

Rockpass risk potential matrix (Naismith, 2002)

Damage status	Interaction risk		
	0–10	11–15	16–20
5	AA*	AA	AAA
4	AA*	AA	AA
3	B	A	AA
2	B	B	A
1	C	B	A

The risk ratings are defined as follows:
AAA — Disaster scenario imminent
AA — Disaster scenario developing
AA* — Damage unlikely to be due to interaction, look for other causes
A — Possible production delays
B — Low likelihood of delays
C — Negligible likelihood of delays

data, deficiencies were identified. This was communicated to the respective managers in both the rock engineering and shaft engineering departments. They were requested to establish a programme to rectify the prevailing situation. Progress with respect to the data collection and development of the required systems is regularly monitored and feedback is provided to the SA Engineers Meeting on a regular basis.

Discussion

Progress

Questionnaires have been completed for 170 main rockpasses and provide a valuable baseline database. This database requires further interrogation in terms of analysing the prevalent contributors to damage.

Rockpass potential risk assessments have been conducted for 170 main rockpasses within the AngloGold Ashanti SA Region. Table VII in an example of an analysis conducted at one of the mines.

Table VII is a summary of the risk potential audits conducted for all the AngloGold Ashanti SA region mines.

The mine audits revealed the following shortcomings:

- Lack of geological sections for each rockpass
- In most cases, the rockpass infrastructure had not been entered into Cadsmine
- Limited measurements of rockpass scaling, mainly due to the difficulty of obtaining these measurements
- Absence of formal procedures for the capturing and communication to mine management of rockpass problems. Generally the approach has been reactive with remedial action plans being developed once the problem has manifested itself
- Limited design information available
- Tendency to only focus on problem areas.

Nineteen per cent of the rockpass legs evaluated are considered problematic. However, for problematic rockpasses there were substantial action and remedial plans in place. This includes the decommissioning of rockpass legs and filling them with waste or rehabilitation.

On several of the mines this was an ongoing process over many years. Generally, this approach has been reactive, with remedial actions being implemented only once a problem had manifested itself. The current focus is very much on active management of rockpasses.

Assessment methodology overview

The questionnaires and mine audits provided a valuable source of information and can be retained as a baseline database. The method used to assess the rockpass risk potential is useful to rank the different rockpasses and assess the possible influence between rockpasses and other excavations.

The work done to date is somewhat limited by the absence of actual rockpass dimension measurements and rockpass geological sections. In addition, the method used does not take into account potentially damaging seismic events. These events could be associated with major structures passing through rockpasses or could be some distance away but damage occurs in highly stressed areas of a rockpass.

Historically, rockpass measurements have been obtained by putting personnel into rockpasses. This is considered hazardous and is conducted only under certain circum- stances. Attempts have been made at remote measurement

Table VII

Waste pass system assessment example SA (Dukes, 2003)

Waste pass segment	(A) Information reliability	(B) Interaction status	(C) Interaction risk (A*B)	(D) Damage status	(E) Risk potential	Comments
900–1050	3	1	3	3	B	
1050–1200	3	1	3	3	B	
1200–1350	3	1	3	3	B	
1350–1500	3	1	3	3	B	
1500–1650	3	1	3	4	AA*	Scaling due to high horizontal stress in N-S direction.
1650–1734	3	1	3	3	B	

Table VIII

Rockpass risk potential summary

Mine	Risk class					Total	%
	AA*	AA	A	B	C		
Great Noligwa	2	9	6	6	2	25	15
Kopanang	0	3	0	7	20	30	18
Moab Khotsong	0	0	0	2	18	20	11
Tau Lekoa	1	0	0	11	0	12	7
Tau Tona	6	1	3	6	25	41	24
Savuka	0	2	0	4	9	15	9
Mponeng	0	1	0	2	24	27	16
Total	9	16	9	38	98	170	100
%	5	9	5	23	58		

systems with limited success. Efforts to develop a remote measurement method that can be conducted routinely continue under the auspices of the AngloGold Ashanti Technology and Innovation Fund.

Efforts are underway to enter all currently available data into Cadsmine and establish geological sections where possible. It is possible to construct a three-dimensional model in Cadsmine, which can be rotated and allows the viewer to assess potential interactions with other excavations and geological structures. This information will assist in completing the risk assessment.

The way forward

The compilation of all outstanding data, including Cadsmine plans and geological sections, is required to complete the main rockpass risk assessment. Geological (e.g. potential wedge failures) and seismic hazards need to be considered in the ongoing risk assessment process.

An effort to quantify the risk in terms of probability of occurrence and consequences is required. This will supplement the qualitative approach used to date, which has focused primarily on establishing a database, identifying potential problem areas and ranking the main rockpass segments per mine.

Formal procedures, for the monitoring of main rockpass problems and effective communication to the appropriate stakeholders, are being developed per mine. This will assist in identifying problems earlier when it is easier and less disruptive to implement remedial actions.

Conclusions

Initially, the rockpass risk assessment was hampered by lack of information. Subsequently, a reasonable database has been established and an initial qualitative assessment has been conducted. Outstanding requirements have been identified and are in the process of being compiled.

The next stage of the risk assessment will need to include geological and seismic hazards in addition to the interaction hazards already identified. A review of the various controls will also be required. A quantitative approach needs to be attempted.

Rockpass problems will undoubtedly continue within the AngloGold Ashanti SA Region. It is therefore imperative, that a continuous risk assessment and risk management programme is implemented and that rockpasses are actively managed.

It has been recognized that proper design with respect to layout and support, quality control during the construction phase and ongoing maintenance can minimize rockpass problems.

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