Mine-wide panel stability monitoring at Anglo Platinum Union JV

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Synopsis

This paper describes the development and implementation of a mine-wide continuous stability monitoring system at the Declines Section, Anglo Platinum Union JV. The Declines Section at Union JV experienced a number of large panel collapses during 2005 and 2006. As well as posing a major safety risk, the panel collapses had a major effect on production since the Declines Section is a semi-mechanized operation. The collapses would often extend into the mechanized strike roadways, resulting in a loss of access to both current and future production faces. The collapses have been largely overcome owing to a change in support design and the implementation of a mine-wide stability monitoring programme. This paper describes the precursors to collapses, which were identified using continuous closure measurements and the remedial measures taken. It also outlines the design and introduction of a robust and reliable monitoring tool, which is now used on a mine-wide basis to provide early warning of large-scale collapses.

Overview of typical rock mass instabilities encountered

The Declines Section at Anglo Platinum Union JV experienced a number of large panel collapses during 2005 and 2006. The workings are relatively shallow (< 400 m depth) and current mining focuses on the UG2 reef horizon. As the Declines Section is a semimechanized operation, with advanced strike drives (ASDs) developed on reef, the panel collapses had a major effect on production. The collapses would often extend into the ASD, resulting in a loss of access to both current and future production faces. A number of monitoring sites were established at the Declines Section and important observations about the large collapses were made. It should be noted that these observations are not applicable to small falls. Most of the large collapses are bound by persistent steep dipping joints, which frequently contained a thick infilling. The almost planar nature of the joints, combined with the presence of the infilling and water in some cases (probably as a result of the heavy rains recorded in late 2005 and early 2006), resulted in low friction angles on these structures. Massive collapses occurred if blocks of certain critical dimensions delineated by these joints were exposed. An example of one of these planar joints and the fallout caused by this are shown in Figure 1.

As the collapses are bound by these steep dipping joints, a distinction can be made between 'stable' and 'unstable' sections in these panels. Figure 2 illustrates progressive slip on one of these joints. The hangingwall area was the unstable portion and measurable rates of closure were recorded in this area. The other side of this joint was stable and no closure was recorded on this side.

Large collapses are often preceded by time-dependent deterioration of the hangingwall and an increase in the rate of closure. Broken elongate support has traditionally served as early warning of the collapses. Closer observation reveals that fresh rock surfaces can be seen on the hangingwall adjacent to joints that are being mobilized. As the unravelling continues, open joints are eventually observed (Figure 3). The falls do not occur instantaneously, but appear to be preceded by a lengthy period of deterioration.

Panel closure measurements at the Declines Section

The time-dependent deterioration of the hangingwall discussed above was accompanied by broken elongate support, which served as a warning of an increase in the rate of closure and a possible impeding collapse. Elongate deformation is nevertheless not a very useful means of providing early warning of the instabilities as the rate of closure preceding collapses at the Declines

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Figure 1—Planar nature of the steep dipping joints as exposed by a large fall in Panel 15S, 4S decline

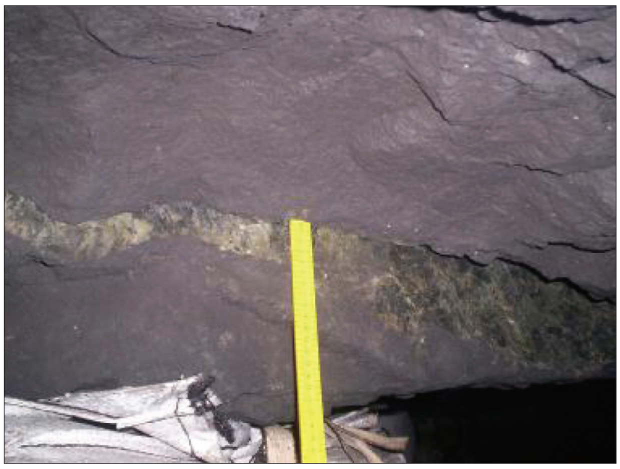


Figure 2—Progressive slip observed on a steep dipping joint at the declines section prior to a collapse

Figure 3—Opening of a discontinuity in one of the ASDs at the Declines Section

Section was very small and too much movement needed to occur before the support gave a clear visual indication of closure. In order to precisely measure panel closure on a continuous basis, and to record the data for later analysis, closure loggers were used. An extensive programme of closure monitoring using the closure loggers was conducted at the shaft during the period 2006/2007. It soon became very clear that the closure measurements are extremely useful to give early warning of the collapses, provided the closure loggers are installed in the correct locations. The sections below illustrate the differences in behaviour recorded for the stable and unstable areas.

Closure instrumentation

An overview of the type of closure instrumentation used in the South African industry can be found in Malan (1999). Owing to the hostile underground conditions, early forms of unprotected electronic instrumentation have never being very successful and the most reliable data has been obtained from mechanical clockwork closure meters. Unfortunately the data are recorded on graph paper and the data analysis is a very tedious and time-consuming process using these meters.

To overcome these monitoring problems, Groundwork Consulting (Pty) Ltd initiated the development of a far more robust and mine-worthy electronic closure logger. An example of the closure logger is shown in Figure 4. The closure is typically recorded at 5 minutes intervals. The data are stored for up to 30 days using an onboard logger and

Figure 4—Continuous closure logger used to measure panel closure (hand-held radio communication unit also shown)

they are then downloaded via a radio communications link to a handheld unit (also shown in Figure 4). As a battery life exceeding nine months is currently achieved, the units are designed to be discarded after this period. An important safety feature of these devices is the ability to download the data remotely. This enables these devices to be installed in areas that might become hazardous in future, allowing the operator to download the data from a safe area. Although very low power transmitters are used, underground communication distances (line of sight) of up to 30 m have been obtained.

As a typical mine might install a large number of these closure loggers, effective data management becomes a critical issue. Appropriate software was therefore developed to capture critical information (Figure 5) and to automatically generate the required closure profiles (see below).

Closure behaviour in stable areas

Owing to the shallow nature of the excavations at the Declines Section, it was found that the rate of closure is very low in the stable areas. This is illustrated by the graph in Figure 6. Similar graphs were obtained for all the stable areas where continuous closure monitoring was conducted.

Closure behaviour in unstable areas

Measurable rates of closure were also recorded in unstable areas and these rates persisted for many days and even weeks before the large collapses occurred. Figures 7 and 8 illustrate closure data from Panel 13S, which eventually collapsed on 26 April 2006. Note that the rate of closure has increased significantly (Figure 7) compared to the low rates in the stable areas (Figure 7).

For Panel 13S, it was found that an increase in rate of closure was recorded for a period of 4 months prior to the collapse. Essential precursory information was therefore obtained from these closure measurements.

A further example of high rates of closure preceding a large collapse was found from the measurements in Panel 4S. The closure logger was installed in this area only after significant deterioration had taken place. High rates of

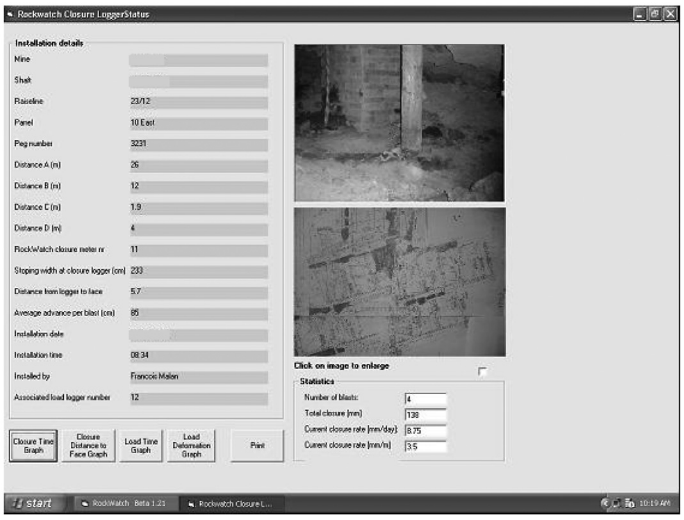


Figure 5—Example of one of the windows of the closure logger software

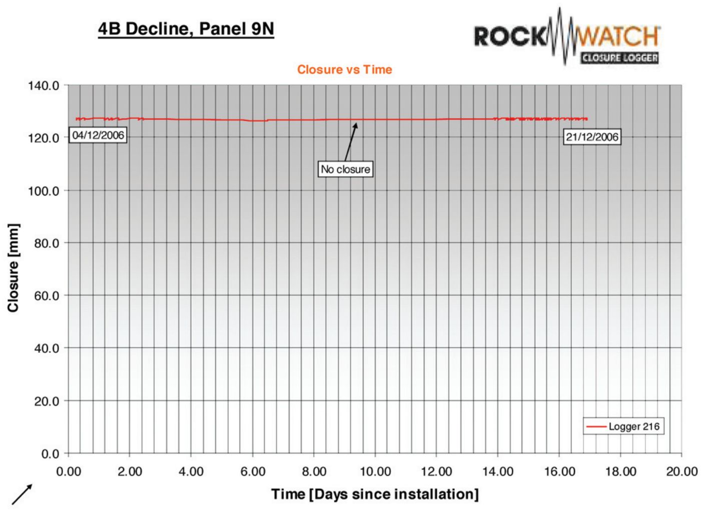


Figure 6—Closure recorded in the back area of a panel at the Declines Section. The rate of closure is very low and this panel remained stable

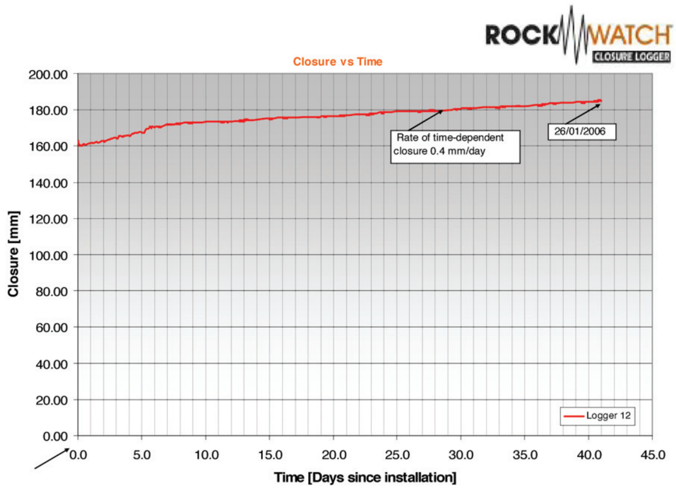


Figure 7—Closure recorded in Panel 13S during January 2006, Union, 4 South Decline , Panel 13S

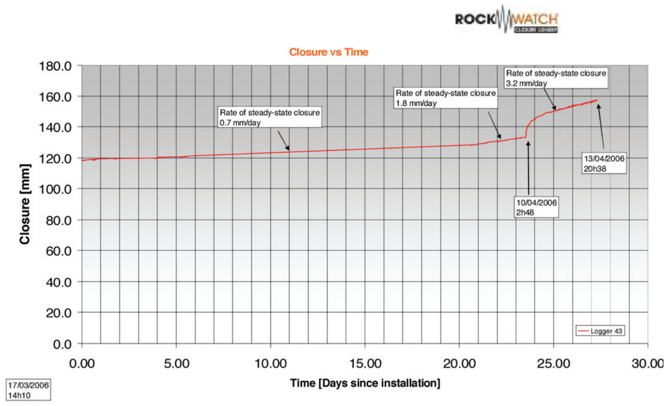


Figure 8—Continuous closure recorded in Panel 13S during March and April 2006. Note how the rate of closure increased after 10 April. This high rate of closure preceded the collapse on 26 April 2006

closure were nevertheless still recorded for a period of 35 days prior to the collapse. As conditions deteriorated significantly during this period, the panel was abandoned early in June and the instrumentation removed. A collapse occurred some time after this. The high closure rates are shown in Figure 8. The total closure measured for this period was 74.3 mm which is very high compared to other closure measurements at the Declines Section. Although the rate of closure was decreasing with time (3.4 mm/day for the first 10 days after installation), it was still as high as 1.1 mm/day for the period from 25 to 30 days after installation.

Control measures

A number of control measures were implemented at the mine to alleviate the problem of large panel collapses. These control measures are described below.

Mine support

A particular problem contributing to the collapses and problems experienced by the mine was the practical difficulties of cutting pillars to the required dimensions with a resulting 'undersizing' of the pillars. To alleviate the problem of undersized pillars being cut, the mine implemented a system of survey lines painted in the panel on the down-dip side of the pillars. This appears to have been very effective in controlling the width of the pillars according to specifications. The support in the panels was also changed from only using 16–18 cm timber elongates, to a system of grout packs and timber elongates. The revised support system is shown in Figure 10.

Routine closure monitoring

In-stope monitoring of closure on a continuous basis has shown considerable promise in significantly enhancing the design and risk assessment tools available to mining operations. Of the various types of in-stope instrumentation, routine monitoring of panel closure on a large scale is probably the most viable as it is relatively easy to install monitoring equipment and no expensive drilling is required. Moving the closure instruments forward as the panel faces move away can also be done with relative ease. Of particular interest is earlier work (Malan and Napier, 2007) in the gold mining industry, which illustrated that continuous closure measurements are an extremely important and valuable diagnostic measure of rock mass behaviour.

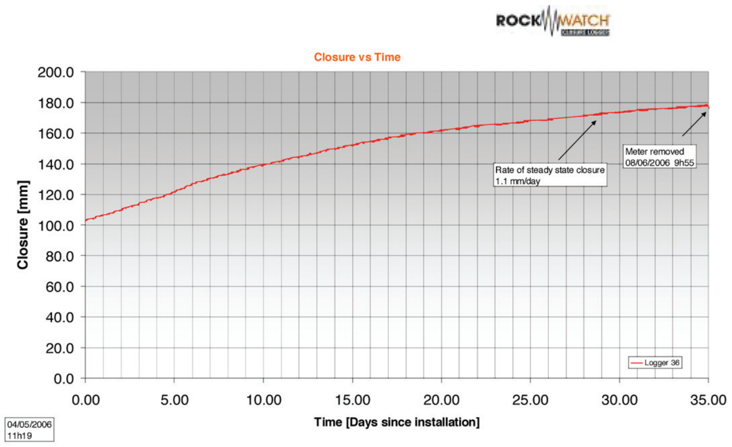


Figure 9—Closure observed in Panel 4S, 4S Decline

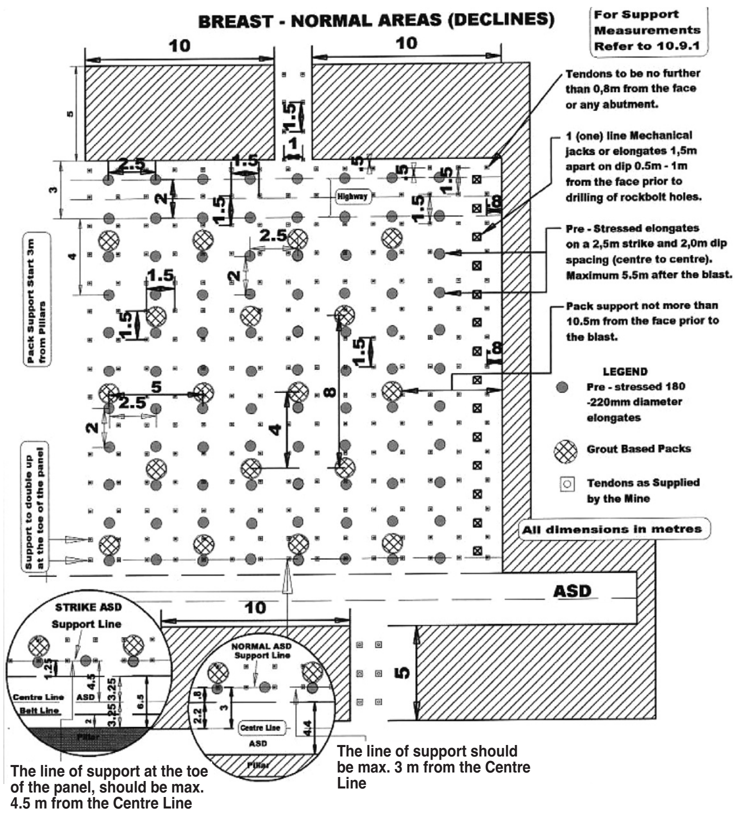


Figure 10—Revised panel support system implemented at the declines section

The closure loggers used in the initial monitoring at the Declines Section were considered to be impractical and too expensive for mine-wide application. A specification was prepared for a more appropriate closure monitoring instrument:

- Immediate indication of significant closure to panel workers
- Indicator with alarm levels, visible from up to 30 m
- Ability to accurately detect movement of as little as 0.25 mm
- Much lower cost than the closure loggers
- Simple to install and monitor
- An operating life of at least nine months.

A suitable instrument, the Closure Telltale, was subsequently developed by Groundwork Consulting (Pty) Ltd and implemented on a mine-wide basis at the Declines Section. The Telltale and its application are described in the section below.

The mine-wide monitoring system

The Closure Telltale

The Closure Telltale is illustrated in Figure 11. The Telltale consists of two springloaded telescopic plastic tubes to hold the instrument in place and a central sleeve containing the movement sensor and other electronics. Relative movement

Figure 11—A photograph of the Closure Telltale

between the hangingwall and footwall is detected by the sensor and converted to a visible traffic light signal transmitted by two LED lights situated on either side of the sensor sleeve. The sensor is able to detect movement of less than 0.25 mm. Other features include the ability to compensate for unnatural extension of the Telltale, an anti-tampering device, various battery conservation methods, and the ability to program alarm levels. The Closure Telltale translates rock movement into green, amber or red LED 'traffic light' signals, which can be easily seen and interpreted by panel workers. This immediate information enables the workers to be more aware of potential rock hazards which would not be seen or detected by normal methods. Based on the database of continuous closure information, it was decided to use 10 mm as the maximum alert level. This resulted in the sequence of LEDs being activated as shown in Figure 12.

Management of the mine-wide monitoring system

A total of nearly five hundred Closure Telltales have been installed across the Declines Section since 2007. A critical part of the mine-wide stability monitoring system is the establishment of management procedures to be followed in the event of the LEDs on the Closure Telltale changing colour. Table I gives an example of these procedures.

In addition to the management procedures, mine personnel keep records of the number, location and colour of the LED on each Closure Telltale during routine visits.

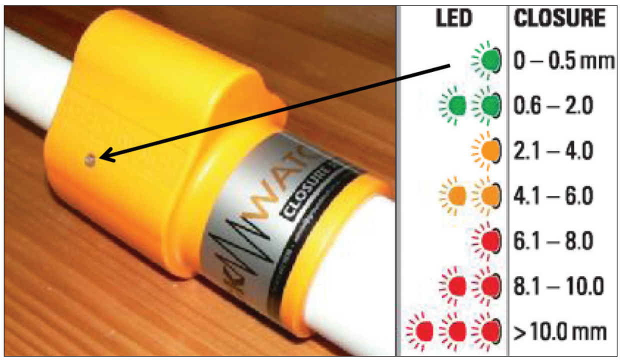
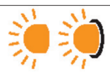


Figure 12—Traffic light LED signals emitted by the closure telltale

Table I

Example of management procedures

LED status (no. of flashes and colour)	Action required
	No action required. Continue monitoring at least once per day.
	No action required. Increase monitoring frequency to start and end of each shift.
	Report change to shift supervisor or mine overseer. Shift supervisor or mine overseer to inspect area. Increase monitoring frequency to at least three times each shift.
	Report change to shift supervisor or mine overseer. Shift supervisor or mine overseer to re-inspect. Increase monitoring frequency to hourly.
	Report change to shift supervisor or mine overseer who must report it immediately to the rock engineer (RE). Continue monitoring hourly.
	Report change to shift supervisor or mine overseer who must report it immediately to the RE. RE to inspect as soon as possible.
	Report change to shift supervisor or mine overseer who must inspect and take decision barricading-off the area. RE to inspect area as soon as possible and to give clearance to continue working or no entry.

Summary

For the period October 2005 to December 2006, an extensive rock mass monitoring programme was conducted at the Declines Section, Union JV. This was in response to a number of large collapses occurring at the mine and the objective was to characterize the rock mass to ensure that appropriate remedial actions could be implemented.

From the data collected, it was found that there is a clear distinction between continuous stope closure behaviour in stable compared to unstable areas. Owing to the shallow nature of the operations, the closure rate in stable areas is very low. In contrast, areas that become unstable are characterised by a measurable rate of closure that persists for many days and even weeks before the collapse occurs, providing an important and valuable early warning of the collapse.

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Owing to the distinct difference in closure behaviour between stable and unstable areas, an improved hazard warning system for the mine was developed based on a large number of Closure Telltale instruments. The instruments utilize a system of different coloured LEDs to warn personnel of changes in closure that might indicate unstable conditions. Approximately 200 of these telltales are currently installed in the Declines Section. The sensitivity of the instruments gives mineworkers the benefit of being able to detect instabilities far earlier than the warning given by elongates (fresh cracks or buckling). It should nevertheless always be borne in mind that these telltales provide displacement data at a particular point and if the spacing between adjacent instruments is too large, potential instabilities might not be detected.

Other remedial actions implemented by the mine were a system of painted survey lines in the up dip portions of the panels to ensure the pillars are cut to the correct size. The support resistance in the panels were also increased by installing grout packs in addition to the timber elongates. These remedial actions appear to be working well. No major collapses have occurred since the introduction of the support changes and the stability monitoring programme. It has been reported that a number of possible collapses have been averted by obtaining early warning signals from the Closure Telltales.

References

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AEL pioneers early warning device for hot holes*

AEL Mining Services, an international leader and innovator in commercial explosives and blasting solutions, has developed and launched Hot Eye, a temperature monitoring device that will assist in detecting and reducing the safety risks posed by hot holes in coal surface mining.

Developed and researched in conjunction with electronics expert, Designs Unique, the patented Hot Eye provides a cost-effective early warning device to the coal-mining sector.

According to Dr Andre Pienaar, AEL's Chief Technologist, burning coal exists at coal surface mining sites often associated with abandoned underground operations. 'When oxygen enters these old workings through openings such as the blast holes and mixes with the coal, it may cause the coal to spontaneously combust before the hole is loaded with explosives.'

A hot hole loading procedure has been developed in partnership with the industry, which is to be used to safely load explosives in any holes with a temperature above 40 degrees Celsius. Holes above 60 degrees are considered hot and attempts are made to cool these holes down with either water or other chemicals such as pyrocool. The temperature of these holes is monitored after cooling and loaded only if the temperature is cooled down below 60 degrees Celsius.

Pienaar adds, 'Holes that are hotter than 80 degrees are abandoned and not loaded. Due to the uncontrolled nature of these underground fires, holes previously cool or those cooled below 60 degrees and loaded with explosives can suddenly be subjected to heat again, exposing the on-bench loading crew to danger. It is AEL's belief that it is a challenge to formulate an explosive product capable of working effectively above 100 degrees Celsius providing a greater safety margin.'

AEL's research and development (R&D) team conducted field trials on the bench probing temperatures and pressures in blast holes as deep as 30 metres. The original testing equipment cost R100 000, which was funded by Coaltech Research Association of South Africa. Informative data about the nature of hot holes was captured during these experiments and the need for an early warning device became apparent.

AEL's newly developed Hot Eye ensures continuous monitoring of loaded blast holes and provides early warning for changes in the blasting conditions, which assists the blaster before and during operations.

Larry Wilson, AEL's Technical Manager, adds, 'AEL has patented the product and is bringing it into the market at an affordable price. AEL has modified the design of the product extensively to make it disposable and highly affordable. It comes with a protective rip tag, which is connected to the battery, and is guaranteed for approximately 8 hours of safe usage. The Hot Eye detector doesn't guarantee safer blasting, but provides a cost-effective tool that is an early warning device for these unpredictable blasting operations.'

An intermittent alarm goes off once the hole temperature reaches 60 degrees and a second, continuous alarm sounds at 80 degrees, indicating that the hole is no longer safe and the operator should evacuate the bench. The hand-held device has a 30 m temperature probe wire, which is dropped down the hole.

Johan Beukes of Coaltech Research Association of South Africa, comments on the launch of Hot Eye, 'This product certainly addresses the safety threat posed by hot holes in coal mining and will go a long way to reducing the risk to the blasting team. We commend AEL's innovation and drive to improve methods and safety of operating in the coal mining industry.' ◆

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