Strategies to Manage Seismicity in a Deep VCR Environment on Mponeng

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Deep level, hard rock mining is intrinsically linked to mining induced seismicity by virtue of the high stresses on the mining faces and abutments. The effects of this seismicity can be devastating, with its severity depending on the event frequency, event size (magnitude) and proximity to current (and populated) workings. At Mponeng Mine, seismicity accounts for some 50% of all mine fatalities and has seen over a hundred people losing their lives in this manner since mining commenced in the mid 1980's. Hence the management of seismicity is the most critical aspect of the risk management strategy. This involves adopting layouts and strategies that can influence both the occurrence of seismicity as well as its effect on workings as and when it occurs.

In recent years Mponeng has adapted its mining layouts, and introduced strategies designed to both reduce the incidence of damaging seismic events, and their effects. These strategies have been very successful, resulting in a dramatic decrease in the number of damaging events (up to 70%) and a reduction in seismic related injuries (75% for lost time and serious injuries) despite an increase in the mining depth.

1 INTRODUCTION TO MPONENG

Mponeng Mine is situated on the West Wits line of the Witwatersrand Basin. Mponeng lies on the Gauteng/North West Province boundary, some 70 km south west of Johannesburg and 8 km south of Carletonville. Mponeng produces gold exclusively from the Ventersdorp Contact Reef (VCR), a quartz-pebble conglomerate characterised by thick reef terraces separated by thin inter-terrace slope reef. The reef is overlain by hard lava of the Ventersdorp Supergroup and lies on strata of the Witwatersrand Supergroup.

Mponeng mines some 28000 m²/month and at an average depth of 2900 m below surface and at an average stoping width of 1.4 m.

Mponeng went into production in the mid 1980's utilising the Longwall Mining Method. Mining spans varied according to geological structures and could reach 300 m between strike pillars (40 m wide). A backfill infrastructure existed but backfill was not utilised everywhere. According to the mining method, minor-throw structures were mined through with large-throw structures being bracketed. Seismicity on major structures and abutments was problematic, and after some ten years of mining, seismicity had been responsible for some eighty fatalities.

In the mid 1990's a decision was taken to make a fundamental change in the mining method from the longwall to the Sequential Grid Mining Method (SGM), which had been recently developed at Elandsrand Mine. The key differences between the two methods are smaller spans with the SGM, dip stabilising pillars replacing strike pillars and pre-developed tunnels rather than follow-behind development. There are several key advantages of the SGM method over the longwall method for the deep VCR environment however most critical has been the improved management of seismicity offered by the SGM method.

The mining method employed by Mponeng could probably best be described as scattered mining with controlled spans via dip-stabilising pillars. The basic layout principals of SGM have been applied but too few current mining levels exist to achieve the desired SGM sequence. Various layout

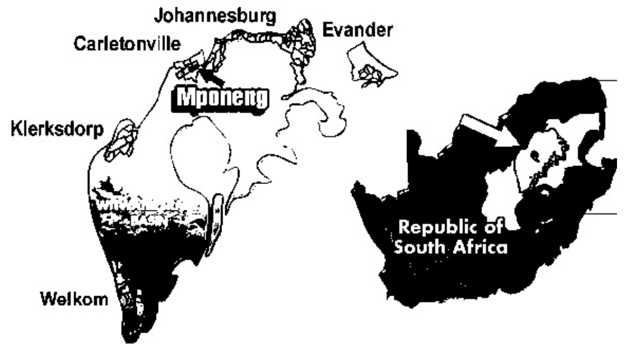

FIG. 1 Regional locality plan

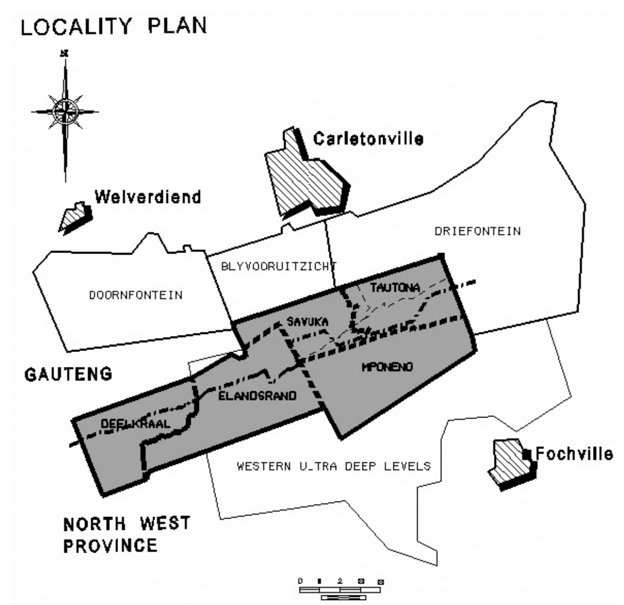

FIG. 2 Local locality plan

and sequencing rules are applied stringently to ensure that extraction sequences are optimised within the grids.

2 MINING INDUCED SEISMICITY

A seismic event is defined as "a sudden inelastic deformation within a given volume of rock." (Jager and Ryder, 1999). These inelastic deformations are caused by the sudden release of elastic strain energy stored in the rockmass surrounding excavations. This strain energy arises from the elastic deformation within the surrounding rockmass due to mining, or more simply, stope closure. Several seismic event mechanisms are postulated, the most common being slip on a major or minor discontinuity in the rockmass. These discontinuities can be geological such as faults, dykes and joints, or mining induced shear fractures along abutments. Strain bursting is another common mechanism experienced on Mponeng whereby a small volume of rock at a stope face fails violently resulting in face ejection.

The Mponeng seismic network records some 1000 events daily ranging from magnitudes of –3 upwards. Only a small subset of these events, referred to as rockbursts, cause damage to workings and injuries to people. Of the events recorded, less than 1% are potentially damaging (200 events/month) and of these some 60-70% occur off-shift with the blast and hence may damage workings but do not cause injury. The damage/injury potential of an event depends on its size (e.g. magnitude), proximity to current working places, ground conditions in working places and the local support installed. Management of seismicity involves reducing the number of damaging events in current workings, this can be done by firstly reducing the overall level of seismicity in their vicinity as well as improving ground conditions and the quality of support systems to lessen the effects of seismic events

Any management of seismicity strategy must consist of two main thrusts: the macro strategy (mine design) addressing mining layout, regional support and extraction sequence; and the micro strategy addressing local support, preconditioning and strata control.

3 MACRO STRATEGY

The key element in a macro strategy for deep mining involves the mine design with respect to spans and regional support. If, as previously stated, seismicity is caused by the strain energy resulting from stope convergence, then strategies geared towards limiting convergence must limit seismicity. Limiting closure can be achieved through the use of regional support, either limiting mining spans via the leaving of stabilising pillars and/or placing extensive face-concurrent backfill.

3.1 Dip Stabilising Pillars

At Mponeng the cornerstone of the macro strategy is the limiting of strike spans to 180 m with 30 m wide dip-stabilising pillars (see Figure 3). This span has shown the ability to generate a maximum magnitude event of 2.3 without any external factors such as major structures interfering. When comparing this layout to the previous longwall layouts one must take into account that the 180 m span is the span at the final stage of extraction and in fact the average span will be 90 m which is well below the 240 m longwall span. This layout is flexible in that the dip pillars can incorporate geological structures and pillars may be shifted. The maximum spans and minimum pillar sizes are however non-negotiable.

3.2 Backfill

Mponeng had mined with backfill in the past on a limited scale, with the change in mining layout in the mid-1990's a decision was taken by management to limit backfilling to special areas. The rationale behind the decision was that the now smaller spans would not generate sufficient stope convergence to load the fill, hence not achieving the loads required for regional support benefits. This is still a moot point in the industry, however Mponeng has made the decision to re-introduce backfill as a vital tool to combat seismicity and to that end has upgraded the plant and shaft infrastructure to increase the available backfill tonnage (see Figure 4). Some 60% of stoping panels are currently filled and this is planned to increase until eventually the entire mine receives face-concurrent fill. The backfill tonnage build-up is reflected in the graph below.

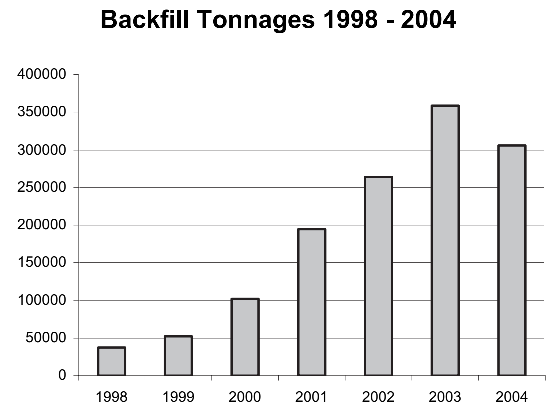

FIG. 3 Backfill Tons 1999 - 2004

With respect to the loads generated in the fill, a backfill bag was instrumented to measure the in situ performance of the fill. The results are shown in the graph (see Figure 5) below and indicate that sufficient loads (>1 MPa) are generated in the fill to provide regional support characteristics despite a reasonably poorly confined test specimen (an open rib was left directly behind the test bag). This occurred after 100mm closure or about 10% strain.

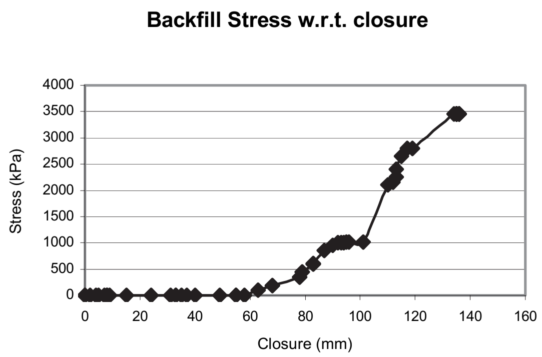

FIG. 4 Backfill stress measured in situ

3.3 Negotiation Of Major Structures

Slip on a geological structure is believed to be the mechanism responsible for most of the large magnitude seismic events occurring in deep level mines. Hence the negotiation of these structures must play a vital role in the management of seismicity strategy. Most large structures will inevitably slip if extensively mined against or near even if bracketed with substantial unmined ground. Extraction sequences and mining layouts can be manipulated however to minimise the effect on current workings, infrastructure, and most importantly, people when these structures do slip. In practice this means mining towards or alongside a feature at an early stage of extraction in the relevant area, i.e. at a "low-span" and then mining away from the feature as the span increases. Bracket pillars are used in a "saw-tooth" arrangement with the first side approaching a structure, intersecting the

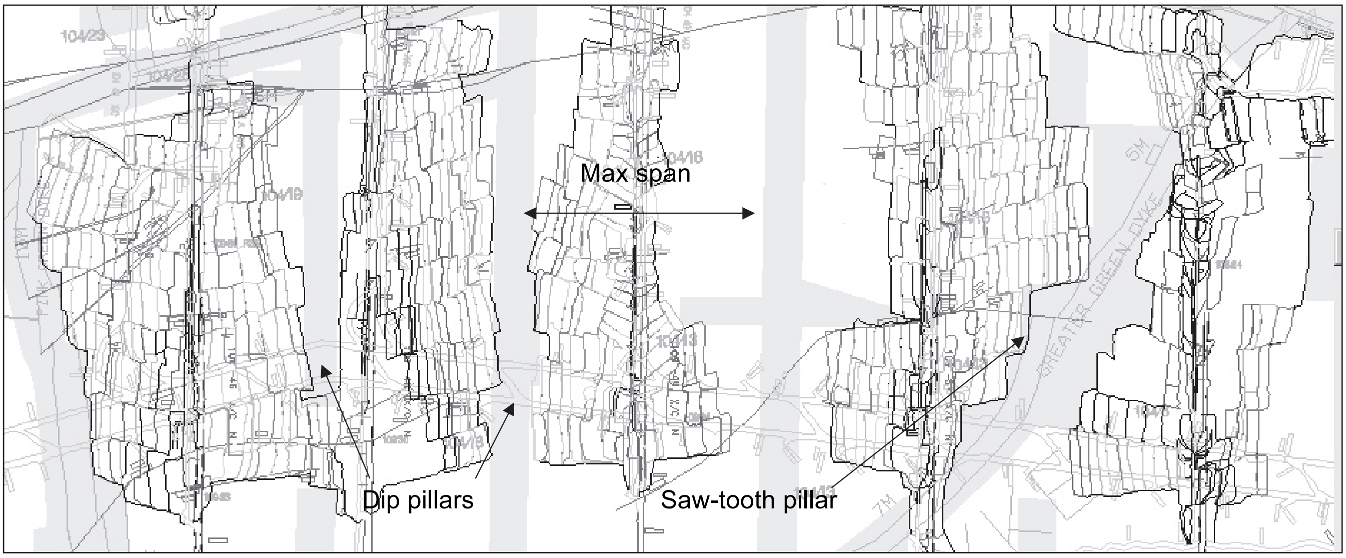

FIG. 5 Typical Mponeng Mine Layout

structure in the "saw-tooth" and the side approaching last "saw-toothing" on a continuous pillar (normally 10-15 m wide). The overall approach angle of the mining faces to a structure is maintained at >30 degrees to ensure the most favourable loading condition.

3.4 Other Sequencing Rules

To manage the face stresses, and mining concentration and volume, the following other rules are applied:

- *Single sided mining.*
  Double sided mining obviously opens up spans twice as quickly and gives rise to stress and strain interaction between panels on either side of a raiseline resulting in a higher seismic response. Hence no double sided mining is done.
- *Controlled converging of panels.*
  Converging panels from opposite raises begin to interact from a seismic point of view it has been suggested that 70 m is the distance at which interaction occurs however this depends on the number of approaching panels, and whether or not there are geological features between the converging areas. At Mponeng the mining of converging panels is discouraged however in exceptional cases done and limited to within 70 m where the layout is favourable with regards to span and structure.
- *Managed inter-panel leads/lags.*
  Excessive lead/lags give rise to localised high stress zones and hence seismicity as well as poor ground conditions in the lagging panel. At Mponeng lead/lags are maintained within 10m at all times.
- *Mine towards solid.*
  The grid mining is performed so as to mine towards the shaft (centre of the mine) first (i.e. at a low span) and then away from the shaft, and from top down (underhand) hence an overall macro sequence of mining towards solid.
- *Controlled mining volumes/concentrations.*
  If mining span determines event size, then mining volume and concentration determines the frequency of event occurrence or activity rate. On Mponeng six crews per raiseline is considered to be the maximum that can be accommodated from an activity rate perspective and is often reduced to four in the final stages of extraction of a grid.

3.5 Tunnel Stability

Tunnel stability has not received much attention in this study due its relative low risk when compared to stoping at Mponeng. Main haulages are pre-developed either in the hangingwall (89,94,104,109 levels) or the footwall (99,113,116,120 levels) at a distance of between 100 and 150m from reef. Since the inception of the Sequential Grid Method, no tunnel instabilities have occurred and the design appears to be suitable. Areas of concern are tunnels passing beneath unmined structures and pillars and tunnelling in shale material. Stringent support systems installed in these areas have ensured that no instabilities have occurred and off-reef stability will not be discussed further.

3.6 Results

The success of a strategy can only be assessed via measured data. The purpose of the macro strategy was stated to be the reduction of seismicity, and as such must be measured accordingly. Mponeng has a good quality seismic network incorporating 35 stations (see Figure 8) and offering sensitivities of anywhere from local magnitude 0 down to –3 in the current working areas.

The quantification of seismicity levels can be done in a number of ways: number of events during the period, number of events in different magnitude ranges during the period, total energy released during the period and total moment during the period. To ensure consistency of data and taking into account the varying historic sensitivities of the network, one must only consider events above a certain magnitude threshold whereby the network will have recorded all such events for the period of analysis throughout the mine. Considering energy and/or moment skews the analysis towards the large events as their energies and moments are orders of magnitude larger than smaller events and in fact they are designed to occur in areas remote from current workings as described earlier.

It was decided to consider only events above 0.5 in magnitude as this population represents the potentially damaging range of events on Mponeng. The number of these events was considered as each represents a separate potentially damaging occurrence. The events were put into various magnitude ranges and furthermore their numbers were normalised according to production volumes as seismicity is driven by production and the mine has seen its production volume doubling from 1996 to 2003.

An analysis of event numbers in four magnitude ranges was conducted from 1996 when the layout change started to the present day. The results represented graphically in Figs. 6-9.

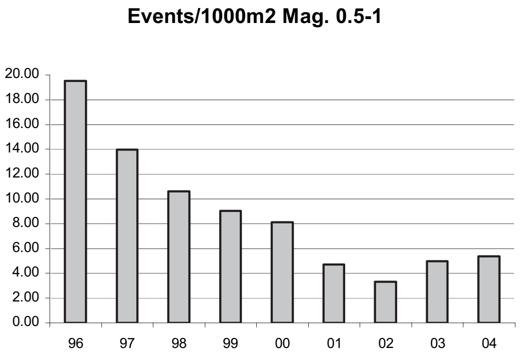

FIG. 6 Events/1000 m² Mag. 0.5-1

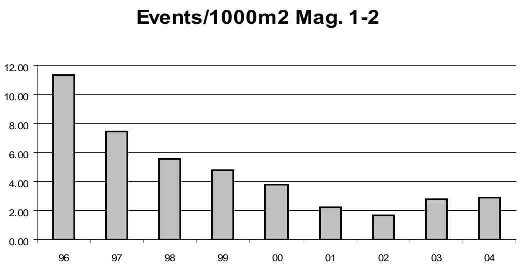

FIG. 7 Events/1000 m² Mag. 1-2

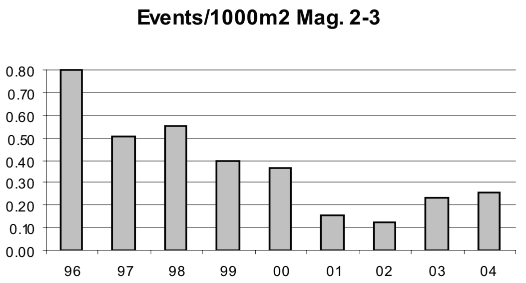

FIG. 8 Events/1000 m² Mag. 2-3

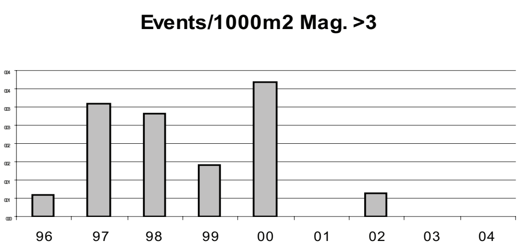

FIG. 9 Events/1000 m² Mag. >3

The decrease in the level of seismicity over the analysed period is striking. Normalised seismicity levels have dropped by some 70-75% in all magnitude ranges except for those > 3 per 1000 m². The magnitude >3 range is not of particular interest as these events tend to occur fairly randomly on large structures remote from current mining faces. Since 1996, no fatalities have been associated with such events and no significant infrastructure damage has been sustained. This is due to the design and if the design rules are broken, there is a risk of these events coming into play again. This decrease has been despite a progressive deepening of mining depth by some 300m on average over the period analysed. This decrease has been a direct result of the implementation of the macro strategy as described. The decrease has been gradual over the period and this is due to the different elements of the strategy being implemented at different times. The overall change in layout from longwall mining to Sequential Grid Mining was made in 1996 but it took several years before sufficient face length was available to optimise extraction sequencing and reduce mining concentration.

Of particular note is the increase in seismic levels in 2003. This is believed to be as a result of a large portion of the stoping coming from mature areas in terms of extracted volume and was expected. Another contributing factor has been the 104 level on the west effectively being mined out-of sequence largely due to development delays due to the methane disaster that occurred in1999. Finally it must be noted that by over-achieving on production targets in 2002 and 2003, face length availability and hence flexibility has resulted in high mining concentrations in certain areas. Specific strategies to combat the increased risk have been implemented and the injury statistics and trends will show their effectiveness.

The result of the decrease in the number of potentially damaging events has resulted in the decrease of seismic risk on the mine. The ultimate deliverable of such a strategy is the reduction of seismic related injuries. Before these trends are discussed, the second aspect of the management of seismicity, the micro strategy, must be discussed as this also influences the injury trends.

4 MICRO STRATEGY

The micro strategy contains those elements that do not influence seismic event occurrence as such but are designed to protect workings and people from the effects of seismic events. These effects manifest themselves in two main mechanisms in stopes: falls of ground due to strong ground motion (shakedown) and face ejection or bursting. The first mechanism occurs when seismic waves “shakedown” loose, unsupported hangingwall blocks in stope panels. The second mechanism involves the mobilising of face slabs into the mining panel due to seismic events in the near vicinity of the panel faces.

4.1 Local Support

During the period under review the main changes in local support has been the move away from pack based systems to elongate based systems. The current system employed consists of elongates throughout the panel with supplementary packs on gully shoulders and backfill in designated areas. Elongates offer stiff support close to the panel face and are superior to packs in preventing the loosening of the hangingwall beam and hangingwall instability. Apart from its regional support qualities, backfill provides local support by confining the elongates and strengthening the system in their usual post-failure phase. Support spacings have become more stringent over the period offering a smaller unsupported area beyond the permanent support and higher support resistances within stope panels.

4.2 Preconditioning

Face-perpendicular preconditioning rose to prominence in the mid-1990’s with various successful and well documented SIMRAC trials, one of which was at Mponeng. In geotechnical environments where face bursting was encountered, this technique was developed to effectively transfer the high stress peak ahead of a mining face further away from the face. This is done by drilling longer holes than the production holes and blasting these prior to the production holes in order to mobilise stress fractures and hence "destressing" the area directly in front of the panel face. Despite the success of these trials, preconditioning was only ever done on an exception basis during pillar mining or problematic extractions. This was due largely to the resistance experienced to the implementation of the technique from the workforce. Scepticism and lack of support from middle management on Mponeng contributed to the non-implementation of the technique. In 2000, face-bursting accidents had become particularly prominent and a decision was taken to implement mine-wide preconditioning.

Three years on from the introduction of preconditioning the decrease in face bursting accidents has been marked. Intensive on-the-job training, additional payments per driller per shift and buy-in and support from top management has seen the implementation progress to a stage where preconditioning is performed in every stope face with every blast. This process has been one of the major challenges of recent years and will continue to rely on management support and on-the-job training and coaching to ensure that it is performed correctly and consistently. It is the belief of the author that mining of the VCR at these depths and below will not be possible without techniques such as this if safety standards are to be improved.

5 INJURY STATISTICS

As stated earlier, the success or failure of any risk management strategy must be determined from accident statistics and trends, as it is these occurrences that are the ultimate consequence of the risk. The rock-related accident statistics for the mine from 1998 to 2004 have been presented in graphical format showing the injury rates in injuries per million man-hours worked per year in three categories.

The categories are:

- Lost time injuries – the injured person is unfit for work for a period not exceeding 14 days.
- Serious injuries – the injured person is unfit for work for a period exceeding 14 days.
- Fatalities – Person is fatally injured.

Despite the fact that seismicity is the focus of the analysis, non-seismic related falls-of-ground statistics have been included to show the effect of the micro strategy in isolation.

The statistics indicate a reduction in injury rates for both seismic and non-seismic injuries for the three classifications. The seismic injury rates have reduced by some 70-75% over the period in the lost-time and serious injury areas, which indicates a good degree of success with the strategies implemented. Perhaps a slightly bigger reduction could have been expected given the combination of the reduction of seismic activity and the reduction in non-seismic injury rates in the same categories (an indication of the effectiveness of local support and strata control alone). Given that rock-related and especially seismic related injuries account for a large percentage of Mponeng's total injuries, this reduction has been significant in lowering the risk profile of the mine and has given mine management confidence in their approach to the sub-109 level stoping planned to begin this year.

Of particular disappointment has been the failure of the strategies adopted to make a meaningful impact on the fatal injury rates in the last few years. These occurrences tend to be fairly isolated and localised in terms of area and number of people affected per incident (a multiple fatality has not occurred for three years). This trend has highlighted the relative severity of seismic related accidents compared with other agencies in their tendency to cause serious harm.

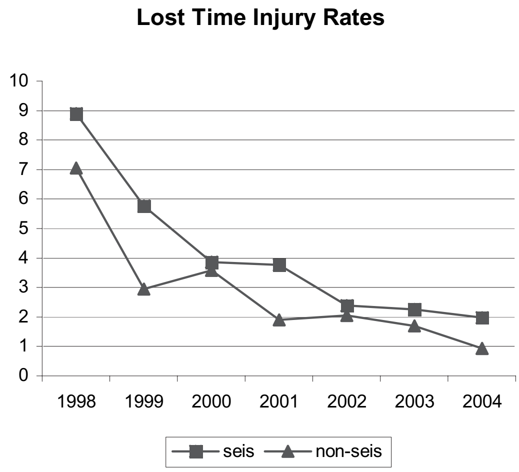

FIG. 10 Lost Time Injury Rates per annum

FIG. 11 Serious Injury Rates per annum

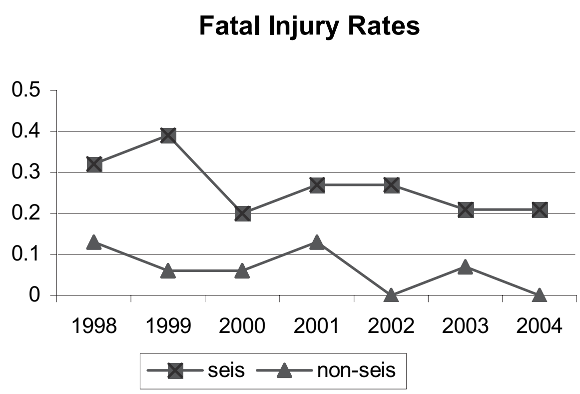

FIG. 12 Fatal Injury Rates per annum

6 CONCLUSION

The management of seismicity will continue to form the cornerstone of Mponeng's risk management strategy as mining progresses deeper and safety targets get more stringent. The results achieved indicate that the dip-pillar based layout adopted has been hugely successful in managing the incidence of seismicity in the deep VCR environment. Significant injury rate reductions have been achieved in recent years to indicate the effects of the seismicity reductions on the panel face. Despite these successes, seismicity levels on Mponeng are high by industry standards and the potential exists for injury and loss of life on a daily basis. It is therefore crucial that the steps outlined in the micro strategy be continually driven to ensure more rockburst-resistant workingplaces.

Backfill will remain a main focus area for the mine in 2005 and beyond as its benefits are coming to the fore and much work is still required to provide fill material to every stope panel. Analysing the fatal accident database indicates accident being confined almost exclusively to the panel face between the last line of permanent support and the face. This is the area that must be better secured if further inroads are to be made in injury rate reduction. To this end Mponeng is experimenting with techniques such as in-stope bolting to improve the stability of this area.

A strong shift towards behavioural-based risk management has occurred on the mine and to that end workingplace audits, strata control training for all, on-the-job coaching and accident/incident investigations are being vigorously pursued in an attempt to improve physical conditions and behaviour of workers at the mining face.

ACKNOWLEDGMENTS

I would like to thank the management of Mponeng for their support in implementing these strategies, and to the Rock Engineering Department for their hard work along the way. I would like to dedicate this paper to the memory of my late colleague Louis de Klerk without whose energy and dedication preconditioning on Mponeng would not have become a reality.

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