Safety in Mines Research Advisory Committee

Final Project Report

The application of a routine moment tensor inversion capability in the development of a new design consideration for the stability of foundations of stabilising pillars in deep level gold mines and pillars in intermediate depth hard rock mines

L.M. Linzer, B.P. Watson, J.S. Kuijpers & E. Acheampong

Research agency:	**CSIR: Division of Mining Technology**
Project number:	**GAP 604**
Date:	**March 2002**
Report number:	**2002-0289**

Executive Summary

Results of SIMRAC project GAP 223 showed that stabilizing pillar-related back area seismicity was not related to the width of the pillar, nor to the dip spans of the stopes supported by the pillar. Pillar associated seismicity initiated in the back area at Western Deep Levels when the APS was, on average, 1.2 times the UCS of the footwall rock. Earlier work showed that pillar foundation (footwall and hangingwall) associated seismicity occurred in the range 65m – 95m behind the face. In both of these cases, the APS was not the full load that the pillar would receive. It was hypothesized that these histories of "foundation failure", are, rather, symptoms of the yielding of the pillar foundation system. Thus the point of interest for design purposes could lie in the yield point of the pillar foundation.

The aim of this project therefore was to use a moment tensor inversion technique to establish design criteria for the prediction of the yield point of stabilizing pillar/foundation system in deep level gold mines.

The project consisted of geotechnical and geomechanical analysis of pillar and their foundations, underground instrumentation and monitoring of pillars and their foundations, numerical analysis of pillar punching and foundation failure mechanisms, seismic analysis of failure mechanisms, development of moment tensor inversion program and verification of the hybrid moment tensor inversion technique.

Geomechanical and geotechnical analyses were undertaken to determine the rock mass condition of *in situ* pillars at Driefontein (dip pillar with backfill) and Tau Tona (strike pillar with backfill) mines. A comparison of the two sites showed similarities in the jointing system. However, the general rock mass conditions in the stope hangingwall of Tau Tona appeared to be better than the Driefontein site.

To allow for characterization of the pillars and rock mass and to determine any deformations caused by stress changes or seismicity, the two sites were monitored.

Detailed numerical modelling work employing FLAC was done to further improve the understanding of foundation failure mechanisms. The dominating effects of boundaries and geological discontinuities on the performance of pillar systems were demonstrated. It was shown that axi-symmetrical punch tests are not representative of typical pillar layouts and a strong need for more realistic laboratory tests has been identified. It was found that typical strength parameters such as friction and cohesion are not sufficient to determine the yield point of a stabilizing pillar system. The post-failure properties need to be accounted for and this, from a practical point of view, is not feasible with current models and techniques. It was also established that in determining the capacity of pillar systems, it is important to detect and analyse the weakest components in the system, which in this case, are bedding planes, joints, faults and weak layers. This may explain the large deformations experienced in the Driefontein pillars.

Using seismic data gathered from the monitored sites, analyses were performed to further improve the understanding of failure mechanisms at the East Driefontein dip-pillar site. The data consisted of waveforms recorded by a micro-seismic system (a blackbox network) installed by Miningtek and of seismograms recorded by the mine-wide seismic system (an ISS network).

Analysis of the spatial and temporal distributions of the events recorded by the micro-seismic network revealed that the GMM data could be grouped into two clusters: a cluster located within

the dip-pillar, and a cluster to the west of the pillar in the abandoned stope that had mined up to the pillar position. Most (58%) of the cluster within the pillar located in the footwall and advanced with the mining face in a face-parallel fashion. Slightly more than half (50%) of the events in the abandoned area were located in the footwall and in a band sub-parallel to the fault system mapped in the area. When the events were filtered in time, it was observed that during the early part of the time sequence, most of the events located in the forming dip-pillar. During the later parts of the time-sequence, the events were no longer confined to the dip pillar, but also located to the west of the pillar in the abandoned working place. These observations possibly lead to the conclusion that the previously clamped fault zone became unclamped towards the end of the formation of the pillar. It is possible that for this site and fault geometry a 'critical pillar width' exists: for widths greater than the critical with, the faults remain clamped, and below the critical width, faults may slip.

The same set of seismograms recorded by the mine-wide seismic system was processed on the mine using the ISS software and then reprocessed using AURA, the seismogram processing analysis program written by CSIR Miningtek. It was found that the magnitudes computed using AURA were substantially larger than those computed using the ISS software, whereas comparisons of energy and moment showed the same order of variation as noted by Richardson & Jordan (2001).

Hybrid moment tensor inversions were performed on two clusters of events. The first cluster analysed consisted of 19 events having relatively large magnitudes (ML > 1.8) recorded in the East Driefontein study area from 1 August 2001 onwards. The second cluster of 101 events was recorded in the vicinity of the East Driefontein dip-pillar from 1 January 2001 to 19 November 2001. The events recorded from 9 to 15 November 2001 were of special interest because these events occurred at the time a jump in the extensometer measurements was observed.

When the fault-plane solutions of the cluster of 19 events were compared with the geological trends, joint orientations, face and pillar geometry, it was found that 8 of the 19 fault-plane solutions could be correlated with the trend of the dyke located 200 m to the west of the pillar line. Since the mining-faces are sub-parallel to the joints and trend of the dyke, it is possible that these geological features became unstable due to mining, resulting in the large events. Four events located to the north of the dip pillar had similar radiation patterns and fault-plane solutions that correlated with the trends of the faulting observed in the area.

Of the 101 moment tensor solutions, over half had radiation patterns indicating strike-slip displacement inferring that the driving stress for these seismic events was sub-horizontal. The high-k-ratio measured in the area and strike-slip patterns indicated that the ambient tectonic stress field played a large role in driving slip on planes of weakness.

A computer program, 'the moment tensor inversion toolbox', was developed to perform moment tensor inversions routinely. The program is described in a general sense and the phases in its development are outlined. The several phases of development made to the program during the course of the project are summarised. The program structure, input data file structure are described and the equations implemented in the code are given.

Finally, the hybrid moment tensor inversion technique was verified to assess the performance of the algorithm under various conditions. Several stability tests using synthetic data were carried out, following which the hybrid MTI methods were applied in a case study situation.

As part of this work, and attached as a separate document, a methodology and guidelines has been developed that allows the determination of which two nodal planes, obtained from moment tensor inversion, is the most likely fault plane.

Acknowledgements

Acknowledgement is made to Dr. S. Spottiswoode of Miningtek for his technical guidance.

Table of Contents

List of Figures

List of Tables

C:\Work\Webupdates\Duncan\Gap604\GAP 604 Chapter 1 2 Underground sites.doc

C:\Work\Webupdates\Duncan\Gap604\GAP 604 Chapter 3 Numerical Modelling.doc

C:\Work\Webupdates\Duncan\Gap604\GAP 604 Chapter 4 Seismic Analysis.doc

C:\Work\Webupdates\Duncan\Gap604\GAP 604 Chapter 5 MTI Program.doc

C:\Work\Webupdates\Duncan\Gap604\GAP 604 Chapter 6 HybridMTI Verification.doc

C:\Work\Webupdates\Duncan\Gap604\GAP 604 References.doc

C:\Work\Webupdates\Duncan\Gap604\GAP 604 Appendix 1 Underground Sites.doc

References