Reply to the comments made by W.D. Ortlepp on the paper 'Strong ground motion and site response in Deep South African Mines', by S.M. Spottiswood and A.M. Milev

The contribution by Ortlepp makes a powerful case for more widespread use of yielding tendons to support tunnels subject to rockbursts. Ortlepp shows that the use of such tendons will work much better in absorbing the kinetic energy of rock ejected from tunnels sidewalls than the non-yielding tendon in general use. Unfortunately it is possible that even yielding support would not have prevented extreme damage such as is shown in Figure 1 of his contribution, but then this truly extreme degree of failure is rare.

Mr Ortlepp correctly indicated that the Milev and Spottiswoode (2005) paper did not provide a complete understanding of the mechanism of damage: it was not our objective to attempt such an exercise but to report on several instrument-year's worth of observations in stopes and to provide some analysis of these observations.

The main message of our paper (Milev and Spottiswoode, 2005) was that a peak particle velocity (PPV) of 2 m/s or 3 m/s can be expected to occur each year in many panels of each of several mines in the Far West Rand. Rock burst support in stopes is typically designed to absorb the kinetic energy of the entire hangingwall of each stope up to a pre-defined height: values of ground velocity are required for support design. The fact that not all of these panels experience severe rockburst damage every year is due to some 'over-design' factors such as the choice of this predefined height, the self-supporting behaviour of the hangingwall, the recommended practice of ignoring the supporting effect of the face and the widespread use of backfill. The fact that many panels do experience rock bursts that are sufficiently severe as to result in injuries and fatalities shows that the support systems, as installed, have failed to achieve their stated objective of providing a reasonably safe working place.

McGarr (2001) pointed out that PPV on faults with weak infilling is limited to a maximum value of about 1.5 m/s. The PPV could be as high as 4.1 m/s in areas of intact rock that are stressed close to failure. Fortunately, lower values of stress change and therefore PPV occur even within the source region as part of the process of stress transfer (Ryder and Jager 2002). In addition ground velocity reduces (attenuates) with distance from the source in a generally well-behaved fashion until the interaction of the seismic waves with the stopes results in the site (amplification) effect that is reported in our paper. The upper bound of 3 m/s for the PPVs measured in our study is consistent with the values given by McGarr.

It was unfortunate that our paper was interpreted by Ortlepp as tending to 'reinforce the sense of complacency which prevails among many members of the rock engineering community. This was not our intention. The section in the introduction of our paper that might have 'reinforced complacency' was reference to an analysis by Haile and Le Bron (2001) of the performance of rock bolts in a simulated rock burst experiment. Ortlepp's contribution consists mostly of an analysis of the work of Haile and Le Bron (2001) rather than of our paper (Milev and Spottiswoode, 2005). He takes issue with the implication in Milev *et al.* (2001) and in Haile and Le Bron (2001) that non-failure of the tendons at the site was evidence in favour of widespread use of such non-yielding support in rockburst conditions. We agree with Ortlepp's analysis that the kinetic energy of a loose sidewall with a thickness of only 127 mm moving outwards at 3 m/s would have resulted in failure of the tendons that were installed. Then why did no tendon actually fail when there was enough kinetic energy for them to fail?

The limited amount of visible damage to rock between support units at the site of the simulated rock burst experiment can be attributed to the good condition of the tunnel and to the relatively low stress regime in the vicinity of the tunnel. Reddy and Spottiswoode (2001) pointed out that the degree of fracturing was commensurate with the estimated field stress of 50 MPa. It is probably true to say that severe rockburst damage such as that shown in Figure 1 of Ortlepp (2006) occurs almost exclusively under conditions of high field stress and/or loose sidewall when driven by high values of ground velocity with accompanying dynamic stresses.

Is the focus on using PPV as the only dynamic parameter that controls rock burst damage valid as is suggested by Ryder and Jager (2002)? Other factors can also play a role. For example, Reddy and Spottiswoode (2001, p. 271) found that the ejected blocks were mostly bounded by pre-existing fractures but also by recent fractures that were probably caused by the blast. As can be seen in Ortlepp's Figure 2 (from Haile and Le Bron, 2001) some areas of newly exposed sidewall are close to vertical and not bounded by bedding planes. Figure 8 of Reddy and Spottiswoode (2001) shows a clear example of such a near-vertical region of newly exposed sidewall. Considering that no fall-outs occurred behind the installed washers through which tendons restrain the sidewall and that the sidewall would have been made safe by barring any loose material before the support was installed, the pre-blast sidewall was held together, at least in some places, by rock strength and not by friction. It is not velocity that breaks rock but stress caused by differential movement. Dynamic stress changes normal to the sidewall are caused by differential acceleration between the sidewall and the material immediately behind the sidewall and not by ground velocity. Field stresses and ground accelerations should also be considered when studying rockburst mechanisms.

Dynamic skin stress is another factor that is generally ignored: see Milev *et al.* (2002) for an analysis of the likely effect of Rayleigh waves on stopes.

Most mining-induced seismic events take place in the fractured rock ahead of the face or on geological structures when they are intersected by mining (Ryder and Jager, 2002). In our study the measurements were taken on the surface of the hangingwall and not within these source regions. Very few direct measurements of the PPV in the source region of damaging events have been obtained. In three cases our instruments were buried or irretrievably lost due to rock burst damage and direct measurements of the ground motion were not possible (Milev and Spottiswoode, 2005, p. 522).

We agree with Ortlepp's opinion that the current understanding of the mechanism of damage resulting from a rockburst is still far from adequate. Our concern is principally that the underlying physics of damage has not been sufficiently explored. To use a phrase favoured by the legal fraternity, we in the rock mechanics business have not sufficiently 'applied our minds to the problem'.

We concur with his concluding plea for more funding for research into the mechanism of rock burst damage as long as this includes a more thorough consideration of the physics behind the process. The Rockburst Management Project (MHSC, 2006) is planned to run until 2010. Hopefully it will create a viable platform for a more fundamental understanding of rock bursts.

In conclusion we would like to express our appreciation to Mr. W.D. Ortlepp for his worthwhile contribution and for the opportunity for further discussion.

References

HAILE, A.T. and LE BRON K. Simulated rockburst experiment – evaluation of rockbolt reinforcement performance. *Journ. of S. A. Inst. Min. Metall.* vol., 101. no. 5, August 2001.

MCGARR, A. Control of strong ground motion of mining-induced earthquake by the strength of the seismogenic rock mass. *Proc. Rockbursts and seismicity in mines*-RaSiM5, South African Institute of Mining and Metallurgy, 2001, pp. 69–73.

MHSC 2006. Minimizing the rockburst risk. SIM 05 03 02, Mine Health and Safety Council, Johannesburg, South Africa.

MILEV, A.M., SPOTTISWOODE, S.M., RORKE, A.J., and FINNIE, G.J. Seismic monitoring of a simulated rockburst on a wall of an underground tunnel. *Journ. of S. A. Inst. Min. Metall.*, vol. 101, no. 5, August 2001.

MILEV, A.M., SPOTTISWOODE, S.M., NOBLE, B.R., LINZER, L.M., M. VAN ZYL, M. DAEHNKE, A. and ACHEAMPONG, E. The meaningful use of peak particle velocities at excavation surfaces for the optimisation of the rockburst criteria for tunnels and stopes, SIMRAC final project report GAP 709. Pretoria: Department of Minerals and Energy, 2002, 139 p.

MILEV, A.M. and SPOTTISWOODE, S.M. Strong Ground Motion and Site Response in Deep South African Mines. *Journ. of S. A. Inst. Min. Metall.*, 2005, pp. 515–524.

REDDY, N. and SPOTTISWOODE, S.M. The influence of geology on a simulated rockburst, *Journ. of S. A. Inst. Min. Metall.*, 2001, pp. 267–272.

RYDER, J.A. and JAGER, A.J. (ed.). Rock mechanics for tabular hard rock mines, SIMRAC, 2002, 489 p. ◆