Safety In Mines Research Advisory Committee
Project Summary

Project Title:	Lead-lag design criteria and seismicity patterns (one volume, 395 pages, incl. 17 appendices)

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Summary

South African tabular gold mining operations typically involve different mining advances in adjacent panels, resulting in panels "leading" or "lagging" each other. It is believed that the lead-lag distance between adjacent panels can affect the distribution and characteristics of fracturing and damage within the mining faces, and may affect roof conditions and hence safety. The normal procedure is to minimise the lengths of lead-lags. Mines have generally adopted layouts where optimum lead-lags between adjacent panels are deemed to be between 5 and 10 m. However, these values are based on experience rather than on detailed measurements or an understanding of the deformation processes. There is thus a need to scientifically quantify the effects of lead-lags on fracturing, stability, support and seismicity to either confirm or modify current design guidelines. The research findings contained in this report aim to provide quantified guidelines on acceptable lead-lag lengths in gold mines.

This report begins with a comprehensive review of the problems associated with lead-lags and resulting strike gully stability. The available published material is summarised in a detailed literature review. Various rock engineering practitioners were interviewed in order to gain their perspectives about the problems surrounding lead-lags. A number of accident reports are summarised as examples of fatal situations where lead-lags were a contributing factor.

Current industry practice around lead-lags is evaluated by reviewing codes of practice (COP) to determine the currently adopted inter-panel lead-lag distances. The stipulated lead-lag lengths range between 4,5 m and 10 m. However, an analysis of in-situ lead-lag lengths shows that the adherence to the recommended standards is seldom above 50%.

Two sets of field measurements were made around lead-lags. Daily closure readings were made in three adjacent panels of a deep-level gold mine site for almost a year in an attempt to relate closure variations to lead-lag length. Detailed fracture mapping around lead-lags was undertaken at 14 sites across eight gold mines representing a variety of reef types, depths and mining methods.

The closure results produced very little useful information about lead-lags, apart from some evidence of an increase in closure rate in the gullies for lead-lags longer than approximately 10 m. The fracture mapping work produced convincing evidence that optimal lead-lags are in the range 4,0 m – 16,5 m, depending on the reef type. However, the guidelines for the selection of lead-lag lengths relate only to quasi-static conditions and any potentially damaging seismic events will impose further restrictions on the choice of optimum lead-lag length.

Seismicity associated with lead-lags was identified from mine seismic catalogues. Moment tensor inversions were used to calculate the source mechanisms of the lead-lag events. Fault plane solutions were used to confirm the selected seismicity as lead-lags events and to determine the focal mechanisms.

At Kloof, most events occurring on the VCR lead-lags were of the oblique-slip type. The largest lead-lag event had a magnitude M_L=1,7 and it occurred on a lead-lag that was only 15 m long. The mechanisms of the lead-lag events were mostly implosive and had lower energy/moment ratios than shear or tensile events occurring on the faces or abutments. Seismic event magnitudes were larger for lead-lags in the range 14 m to 23 m. There was evidence of a seismic event occurring on a flat-dipping failure plane that cut obliquely across the corner of a 22 m long lead-lag.

At Tau Tona, none of the selected seismic events occurred on inter-panel lead-lags. However, seven of the 21 fault plane solutions were associated with abutments on the lower Carbon Leader Reef. The events occurring on abutments were predominantly oblique-slip or dip-slip type. The mechanisms of the abutment events were mostly shear events. The event magnitudes were larger for abutments lengths in the range 36 m to 52 m. A possible corner-cutting fracture was noted for one seismic event, which occurred in the corner of a 52 m long pillar abutment.

The effect of varying lead-lag length on the rock mass was simulated in two stages of numerical modelling: elastic modelling using MINSIM and inelastic modelling using Elfen. The results from the MINSIM modelling showed, as expected, that increases in lead-lag length resulted in large increases in the vertical stresses, ERRs and elastic convergence. It was concluded that short lead-lags should be used to reduce the vertical face stresses and ERR. The intensity of fracturing and the absolute values of the vertical stresses and ERRs cannot be predicted by MINSIM. However, the results seem to indicate extreme vertical stresses and ERRs for lead-lags greater than 10 m at 3000 m depth.

The discrete fracture generation capability of Elfen was used to simulate damaged and failed regions around lead-lags. The Elfen model showed that damage increases as the lead-lag distance increased. However, the modelled fracture extents were much smaller than the underground observations because the increase in the friction angle (with increasing plastic strain) of the Mohr-Coulomb strain softening model needs to be less severe than has been modelled here. Further work is required to carefully calibrate the material model with both lab test data and underground observations to obtain a reliable indicator of the extent and magnitude of damage.

While the results are not definitive, the work undertaken in this project indicates that the currently adopted lead-lag guidelines of 4,5 m to 10 m stipulated in COPs are similar to the findings in this project. In particular, the fracture mapping work provided some compelling results. It is proposed that the following lead-lag distance ranges be adopted in the South African gold mining industry:

Reef type	Approx. depth (m)	Proposed optimal inter-panel lead-lag distances for quasi-static conditions from fracture mapping analysis (m)						
		RMR	MRMR	Q-rating	Fracture spacing	Siding-parallel fractures	Wedge analysis	Current practice
VCR	2400 to 3000	Lack of sufficient data	Lack of sufficient data	Inconclusive	Lack of sufficient data	5,5–10,5	Inconclusive	5–10
CLR	3200					9,5–16,5		10–15
Vaal	2300					4,0–9,0		5–10
Basal	2000 to 3200					6,0–11,0		5–10
All reefs	**2000 to 3200**	**15**	**17**		**<16,5**	**6,5–12,0**		**5–15**

For reef types not addressed in this project, a match for similarities in geotechnical settings should be checked against the four reef types analysed and the appropriate range chosen. If no match is established, the ranges suggested for the combined reef should be used. Although not extensive, the seismic findings from the Kloof analysis seem to corroborate the guidelines derived from the fracture mapping work. The Elfen model needs to be further calibrated for the study of fracturing around lead-lags before it can be successfully used as a forward modelling tool to determine optimal lead-lag lengths during mine design.