REPORT NO.: 2004-0083
TO BE PUBLISHED IN 'INTERNATIONAL JOURNAL OF ROCK MECHANICS AND MINING SCIENCES, VOLUME 41, ISSUE 3, APRIL 2004, PAGE 544.

THE APPLICATION OF SHORT ROCKBOLTS IN ULTRADEEP TABULAR STOPING

M.K.C.Roberts[1], R.A. Lamos[2], S.K.Murphy
[1]CSIR Miningtek, mroberts@csir.co.za
[2]CSIR Miningtek, rlamos@csir.co.za

Abstract: Most rock related fatalities and injuries in South African gold mines occur in the stope face area. These mines generally do not use rockbolts to support this area. This paper describes short rockbolt applications in the stope face area in a narrow tabular ultradeep Carbon Leader stope. The project began with the geotechnical definition of the generic Carbon Leader Reef hangingwall and the design of a short rockbolt support system to stabilise this hangingwall. In the paper the implementation efficiency of the bolting system is described. The quantification of ground conditions was undertaken by comparing bolted and unbolted portions of the stope face. This was done by using hangingwall profiling and stoping width measurements. Some numerical modelling is presented showing the benefits of bolting in the Carbon Leader Reef geotechnical area. The paper then briefly covers short bolt reinforcement design problems that still have to be overcome, such as quantifying and matching the bolt requirements of strength and yieldability and the reinforcement zone of influence of bolts, which is related to bolt spacing, in seismically active conditions. Empirical data under seismically active conditions is still required for rockbolt design purposes.

Keywords: rockbolt, ground improvement, tabular stopes, ultradeep, seismicity

1. INTRODUCTION

A comparative study of rockbolted and non rockbolted Carbon Leader hangingwall was undertaken at a deep Carbon Leader mine. The panels are stoping at approximately 3 km depth.

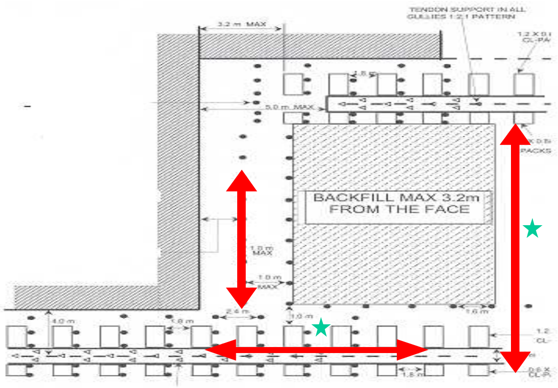

Figure 1. Typical schematic deep breast mining layout.

Figure 1 above shows a typical schematic breast mining layout employed in deep tabular mining. The red lines show positions where the effectiveness of rockbolting could be studied.

The panels are employing backfill, grout pack and prestressed yieldable elongate permanent support. The planned stoping width is 88cm. The face lengths are approximately 35m per panel. On a two-day cycle, in backfilled stopes, closure could be as high as 50 mm/day at 1-2m from the face. As measured by Malan et. al. 200 . The dip of the reef is about 22°.

2. STRATIGRAPHY, DISCONTINUITIES AND GENERIC HANGINGWALL ROCKMASS CLASSIFICATION

For modelling and design purposes a generic hangingwall for the Carbon Leader Reef was described by Roberts et. al. (1) 2002 and is shown in Figure 2.

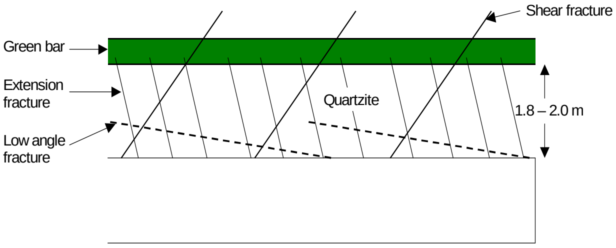

Figure 2. The generic Carbon Leader hangingwall.

The fracture classification work of Adams et al 1981 has been incorporated in the generic model of the hangingwall. This shows the immediate hangingwall stratigraphy as fine to medium-grained trough crossbedded poorly bedded quartzite, overlain by the Green Bar, usually 1-2.5 m thick. This stratigraphy will be intersected by extension and shear stress fractures due to the depth of mining.

Figure 3 shows a typical Carbon Leader Reef hangingwall in the area where the rockbolting was undertaken.

Figure 3. Carbon Leader Reef hangingwall.

The stress fracturing in the Carbon Leader Reef hangingwall can be intense and complex. Other gold reefs that have characteristics of the Carbon Leader Reef generic model are the Basal Reef and the Main Reef.

3. FALLS OF GROUND

In Carbon Leader Reef stopes, a fall of ground can occur due to gravity or due to the ejection of rocks as a seismic wave interacts with the stope. Figure 4 shows the cumulative percentage of fallout thicknesses due to gravity that have caused fatalities. Figure 5 shows the cumulative percentage of fallout thicknesses due to seismicity that have caused fatalities.

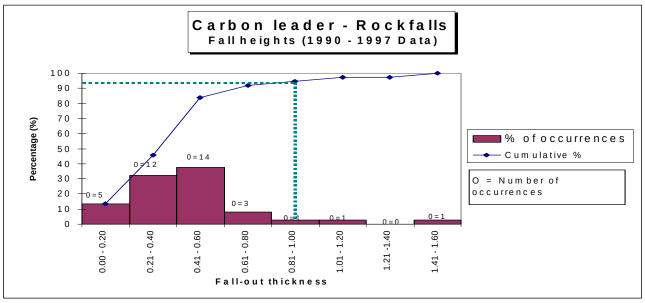

Figure 4. Carbon Leader fall thickness, gravity induced.

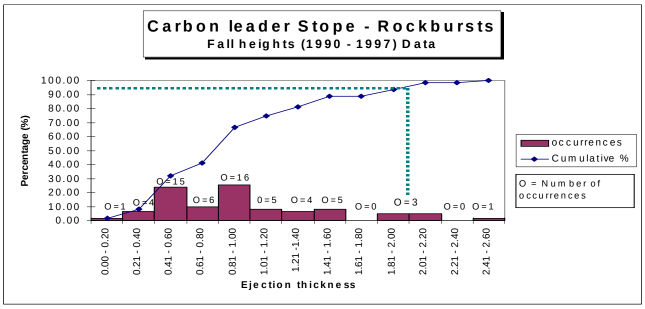

Figure 5. Carbon Leader fall thickness, seismically induced.

From data such as that shown in Figures 4 and 5 a support resistance criterion and an energy absorption criterion can be determined by using the fallout heights at the 95% cumulative fallout thickness for rockfall and rockburst conditions respectively. Conventional stope support systems are required to meet these criteria. For the purpose of the rockbolting support system, it was decided that it would be required to meet a support resistance criterion and an energy absorption criterion by using the fallout heights at the 50% cumulative fallout thickness, as well as to provide a measure of reinforcement. This potential was alos indicated by the previous laboratory (physical) modelling done by Roberts et. al (1) 2002.

4. ROCKBOLT DESIGN

The design of the rockbolt support system was strongly influenced by the generic Carbon Leader Reef model shown in Figure 2. Both suspension and beam building was required of the rockbolt support system, as indicated in Figure 6. Roberts et. al (2) 2002.

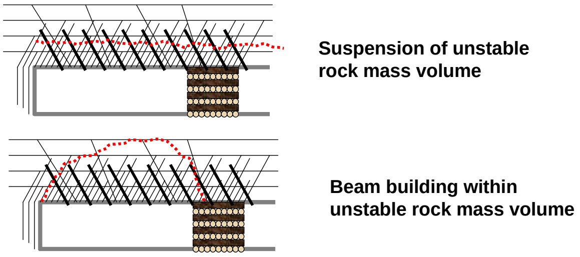

Figure 6. Rockbolt suspension and beam building for supporting the stope face.

In addition, the need for large base plates was recognised due to the severely fractured nature of the ground. Figure 7 shows an example of a seismically induced fall of ground at the top of the face of the panel, where 0.3 to 0.6m rockfalls accompanied a seismic event. The conical zone of support influence on top of the yieldable elongate can clearly be seen. This illustrates the point that the introduction of even relatively short rockbolts with a staggered spacing and large base plates between the elongates, giving areal support and reinforcement between the elongates.

Figure 7. Seismically induced fall of ground at the top of the panel face area

The rockbolt support system consists of 1-1.2m long resin grouted rockbolts spaced 1 m by 1 m on strike and dip, and installed 60° towards the stope face. The rockbolts are of 200 kN ultimate tensile strength and are 20mm in diameter. They are resin grouted with fast set MINOVA resin on a spin to stall principle in a 28mm diameter drill hole. Post-tensioning is done ideally before the blast. Large bearing plates of dimensions 20cm by 30cm are used to increase the areal coverage of the support system.

5. UNDERGROUND IMPLEMENTATION

A South African low stoping width drillrig was modified for the bolting application.
The daily available bolt installation time was 4hours and 15 minutes. Two drillrig operators per machine are necessary and five drillsteels (short to long) are generally necessary to drill one rockbolt hole. The system is labour intensive and only 10 bolts per shift could be installed. Figure 8 shows an example of the spin-to-stall installation of such a rockbolt, 0.3m from the actual stoping face.

Figure 8. Spin-to-stall installation of a roofbolt in the hangingwall close to the stope face.

Figure 9 shows a rockbolt and bearing plate in the stope face area directly after the blast.

Figure 9. A rockbolt and bearing plate after the blast.

6. EVALUATING THE EFFECTIVENESS OF THE ROCKBOLT SUPPORT SYSTEM

Hangingwall profiling was undertaken in order to compare rockbolted and non rockbolted areas to quantify the change in ground conditions. Figure 10 shows three typical hangingwall profiles where bolting had been done. Note the relative smoothness of these profiles compared to the unbolted profiles shown in Figure 11.

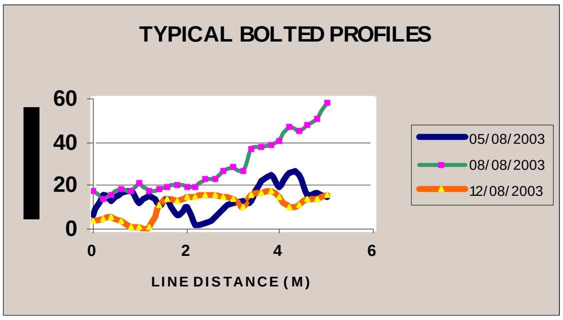

Figure 10. Partially bolted hangingwall profiles.

The same areas at the top of panel were profiled afterwards without bolting and show higher roughnesses as a result of larger fallouts. The difference is an indication that the rockbolted portions of the stope face hangingwall are controlling fallout from the hangingwall.

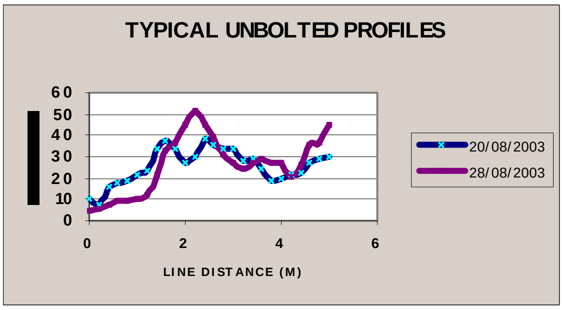

Figure 11. Unbolted hangingwall profiles.

Hangingwall profiles can be used to characterise the roughness characteristics of stope hangingwall areas. Profiles taken in another stope will show their own characteristic properties. Currently this is under investigation utilising fourier transform wave analysis methods.

The mining height was measured in the portions of the stope face where bolting had been installed and compared to areas where bolting had not been installed. The mining height decreased by approximately 10 cm for the bolted case. Although other factors influence mining height, the reduction is a likely indication that fallout during and after the blast was reduced.

Time-dependent fallout was monitored in a dip gully. Profiles were taken along the gully which had both bolted and unbolted sections. The profiling was repeated three weeks later and the two results are compared in Figure 12. Clearly less fallout had occurred in the bolted hangingwall area.

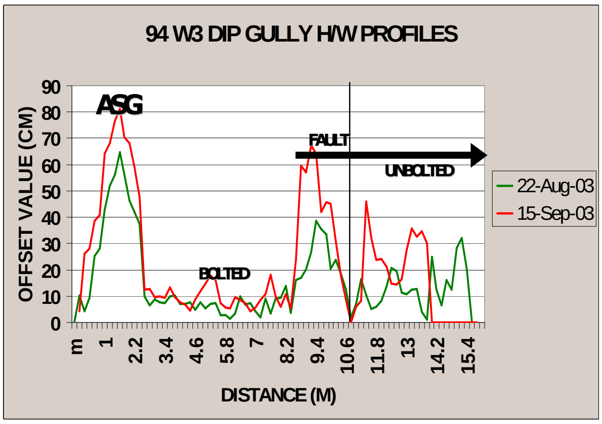

Figure 12. Time dependent hangingwall profiles (bolted/unbolted)

The bolts were installed early in the face area and the results imply that the bearing plates provide better areal coverage than the conventional bolting, which is installed slightly later, after footwall sliping.

7. NUMERICAL MODELLING

Numerical modelling utilising the ELFEN code was done, simulating dynamic loading of the generic roofbolt pattern, as shown in figure 13, after Roberts et. al (1) 2002.

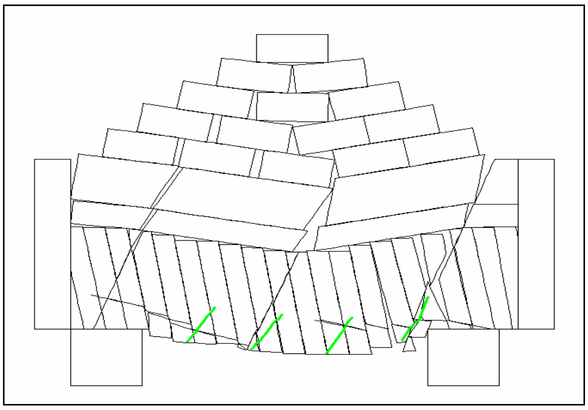

Figure 13. ELFEN model simulating dynamic loading of the generic roofbolt pattern

Figure 14 shows the difference in energy absorption capacity, comparing an unbolted to bolted model.

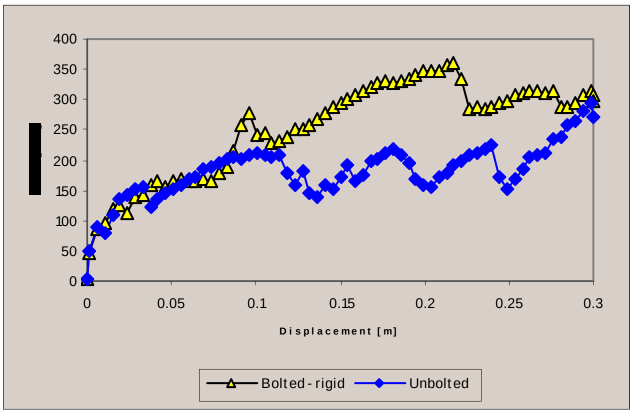

Figure 14. Unbolted/bolted ELFEN model load-displacement curves

The model shows an approximate energy absorption potential of 15 kJ per square metre for the bolted system compared to the unbolted case. The energy absorption components are from the bolt system and reinforced rockmass together. The model is being adjusted to include backfill as support as well as a stiffer lateral abutment confinement, to give more realistic results.

8. CONCLUSIONS

It has been shown that 1m long rigid bolts can be installed in an 85 cm stoping width. The labour intensive support system could find applications in areas where hangingwall problems are experienced. One particular area where a significant difference can be made is the installation of the bolts at strike gully face areas (early bolt installations).

The rockbolting pattern that was installed in the hangingwall of the Carbon Leader stope appears to reduce hangingwall fallout and falls of ground. This is strongly indicated by the smoother hangingwall profiles and the reduction in the mining height in the rockbolted sections. No significant rockburst occurred during the rockbolting trial but small seismic events would have added some cumulative damage indicating that the rockbolt support system was effective in reducing gravity falls and falls from the cumulative damage from small seismic events.

What was not tested was the effectiveness of the rockbolting system in the event of a damaging rockburst. The numerical modelling indicates that there is the potential of the rockbolting system to limit damage by having the ability to absorb approximately 15 kJ/m^2 of energy should a damaging rockburst occur. Therefore the evaluation of this rockbolting support system in severe seismic conditions is work that is still required to be done.

9. ACKNOWLEGEMENTS

The authors would like to thank the Future Mine Collaborative Research Programme who provided financial support for this work and for permission to publish this paper.

10. REFERENCES

Adams, G.R., Jager, A.J. and Roering, C.1981 *Investigation of rock fracture around deep-level gold mine stopes.* Proc. 22nd US Symp. Rock Mech. Boston, M.I.T.

Malan, D.F. 1999 *Closure measurements in tabular excavations: Avoiding the pitfalls* Proceedings of the 2nd Southern African Rock Mechanics symposium, SARES 99, Johannesburg

Roberts, D.P., Roberts, M.K.C., Acheampong, E.A. 2002 Improved understanding of the use of short tendons for stope support under rockfall and rockburst conditions (Phase I). SIMRAC GAP 849 final project report.

Roberts, M.K.C., Acheampong, E., Jager, A.J., Urcan, H., Lamos, R.A., Noble, B. 2002

Rockbolt support in the stope. FUTUREMINE final project report, Futuremine Collaborative Research Programme.