6th International Symposium on
GROUND SUPPORT
in mining and civil engineering construction

Editors:
T.R. Stacey and D.F. Malan

30 March to 3 April 2008

Table Bay Hotel, Cape Town
SAIMM PUBLICATIONS

THE MONOGRAPH SERIES

M1 Lognormal-De Wijsian Geostatistics for Ore Evaluation
   (2nd ed 1981) D.G. Krige

M2 An Introduction to Geostatistical Methods of Mineral Evaluation
   (2nd ed 1981) J.-M.M. Rendu

M3 Principles of Flotation

M4 Increased Underground Extraction of Coal

M5 Rock Mechanics in Mining Practice

M6 Assay and Analytical Practice in the South African Mining Industry
   (1986) W.C. Lenahan and R. de L. Murray-Smith

M7 The Extractive Metallurgy of Gold in South Africa,
   2 volumes (1987) Edited by G.G Stanley

M8 Mineral and Metal Extraction — An Overview

M9 Rock Fracture and Rockbursts—an illustrative study
   (1997) Edited by W.D. Ortlepp

THE SPECIAL PUBLICATIONS SERIES

SP1 Proceedings, Underground Transport Symposium
   (1986) Edited by R.C.R. Edgar


SP3 Treatment and Re-use of Water in the Minerals Industry (1989)

SP4 COREX Symposium 1990
   (1990) Edited by H.M.W. Delport and P.J. Holaschke

SP5 Measurement, Control, and Optimization in Mineral Processing
   (1994) Edited by H.W. Glen

SP6 Handbook on Hard-rock Strata Control
   (1994) A.J.S. Spearing

SP7 Rock Engineering for underground coal mining

SUPPLEMENT TO THE SAIMM JOURNAL

Edited by H.W. Glen
THE SYMPOSIUM SERIES

S1 Mathematical Statistics and Computer Applications in Ore Valuation (1966)
S3 Application of Computer Methods in the Mineral Industry (APCOM 1973) Edited by M.D.G. Salamon
S4 Infacon 1974 Edited by H.W. Glen
S7 The Planning and Operation of Open Pit and Strip Mines (1986) Edited by J.P. Deetlefs
S8 GOLD 100: Proceedings of the International Conference on Gold (1986)
  Volume 1: Gold Mining Technology Edited by H. Wagner and R.P. King
  Volume 2: Extractive Metallurgy of Gold Edited by C.E. Fivaz and R.P. King
  Volume 3: Industrial Uses of Gold Edited by G. Gafner and R.P. King
S9 APCOM 87: Proceedings of the Twentieth International Symposium on the
  Volume 1: Mining Edited by L. Wade, R.W.O. Kersten and J.R. Cutland
  Volume 2: Metallurgy Edited by R.P. King and I.J. Barker
S10 International Deep Mining Conference (1990)
  Volume 1: Innovations in Metallurgical Plant Edited by G.A. Brown and P. Smith
  and
  Application of Materials Engineering in the Mining Industry Edited by B. Metcalfe
S11 Infacon 6 (Incorporating Incase) (1992) Edited by H.W. Glen
S12 Massmin 92 Edited by H.W. Glen (out of print)
S13 Minefill 93 Edited by H.W. Glen
S14 XVth CMMI Congress Publications (1994)
  Volume 1: Mining Edited by H.W. Glen
S15 Surface Mining 1996 Edited by H.W. Glen
S16 Hidden Wealth (1996) Edited by H.W. Glen
S17 Heavy Minerals 1997 Edited by R.E. Robinson
S18 The 8th International Platinum Symposium (1998)
S19 Mining in Africa '98
S20 Extration Metallurgy Africa '98
S21 Sixth International Symposium for Rock Fragmentation by Blasting (1999)
S22 Metallurgy Africa '99
S23 Heavy Minerals 1999 Edited by R.G. Stimson
S24 Tunnels under Pressure Technical Editor T.R. Stacey
S25 Mine Hoisting 2000
S26 Coal—The Future (2000)
S27 The Fifth International Symposium on Rockburst and Seismicity in Mines (RaSim 5) (2001)
S29 XIV International Coal Preparation Congress and Exhibition
S30 Surface Mining 2002—Modern Developments for the New Millennium
S31 IFSA 2002, Industrial Fluidization South Africa
S32 ISSA/Chamber of Mines Conference—Mines and Quarries: Prevention of Occupational Injury and Disease
S33 ISRM—Technology Roadmap for Rock Mechanics
S34 Heavy Minerals Conference 2003
S37 Tenth International Ferroalloys Congress INFACONX 2004
S38 Deep and high stress mining 2004
S39 ‘Platinum adding value’ 2004
S39A Base Metals—Southern Africa’s response to changing global base metals market dynamics 2005
S40 Strategic versus Tactical approaches in mining 2005
S41 Best practices in rock engineering SARES 2005
S42 IFSA 2005 (Mintek)
S43 Southern African Pyrometallurgy 2006 International Conference
S44 Stability of rock slopes in open pit mining and civil engineering situations
S45 ‘Platinum Surges Ahead’ 2006
S47 Fourth Southern African Base Metals Conference ‘Africa’s base metals resurgence’
S48 Heavy Minerals Conference, 2007
S49 Cave Mining Conference, 2007
S50 International Symposium on Lead and Zinc processing – Lead & Zinc 2008
The papers printed in this volume have been reproduced directly from copy supplied by the authors. The Institute therefore takes no responsibility for any errors or changes that may have occurred in the transferring of documents between systems. Wherever possible, quality control checks have been exercised.

TECHNICAL REVIEWERS

All papers included in this volume were subjected to review. A technical and critical review of each paper was carried out by two technical reviewers. The following is the list of reviewers used and their affiliations.

Mr A. Boniface
Gautrain Rapid Rail Link

Dr D.F. Malan
Groundwork Consulting

Mr D. O’Connor
Minova RSA

Dr E.J. Sellers
AEL

Prof. T.R. Stacey
University of the Witwatersrand

Printed by Camera Press, Johannesburg
FOREWORD

Ground support is a very important topic in both mining and civil engineering fields. It has been the subject of several symposia in the past, and this symposium is the sixth in a series of international events dealing with this specialist subject. These symposia have been organised on an ad hoc basis in different parts of the world, previous symposia having been held in the following locations:

- 1983 in Luleå, Sweden
- 1992 in Sudbury, Canada
- 1997 in Lillehammer, Norway
- 1999 in Kalgoorlie in Australia
- 2004 in Perth, Australia

Ground support is used extensively in both civil and mining environments, but commonly there is insufficient interaction between these two disciplines. In both fields significant developments in ground support take place regularly, and miners have a lot to learn from their civil colleagues and vice-versa. South Africa, with a strong mining tradition and also a country with a rapidly developing civil infrastructure, is an appropriate location for such interaction to take place.

This 6th International Symposium on Ground Support in Mining and Civil Engineering Construction has been organised jointly by the Southern African Institute of Mining and Metallurgy (SAIMM) and the South African National Institute of Rock Engineering (SANIRE), and is also an official Regional Symposium of the International Society for Rock Mechanics.

The Symposium has attracted good international participation and we are grateful to all presenters and delegates for taking time out of their busy schedules to come and share their knowledge. A substantial, good quality volume of proceedings has resulted, and we hope that all will benefit from this event.

Thanks are due to the Organising Committee and to the Secretariat of the Southern African Institute of Mining and Metallurgy for the organisation.

T.R. Stacey and D.F. Malan
Co-Chairmen of the Organising Committee
The organisers of the symposium wish to thank the following sponsors for their support

-oOo-

Atlas Copco

BASF Construction Chemicals

Duraset

Gold Fields

Maccaferri

Minova RSA

New Concept Mining
Contents

Keynote Address: What happened to the mechanics in rock mechanics and the geology in engineering geology? 
P.J.N. Pells ................................................................. 1

Application of modified Hoek-Brown transition relationships for assessing strength and post yield behaviour at both ends of the rock competence scale 
T.G. Carter, M.S. Diederichs, and J.L. Carvalho ........................................ 37

The residual strength of a 2.5 m wide Bushveld Merensky Reef crush pillar 
B.P. Watson, S.M. Mosomane, J.S. Kuipers, and D.P. Roberts .................... 61

A numerical study of the shotcrete-rock interaction 
L. Malmgren and E. Nordlund .............................................................. 79

Numerical modelling of tunnel liner and fracture interaction 
D.F. Malan and J.A.L. Napier ............................................................... 91

Field observations and numerical studies of horizontal stress effects on roof stability in U.S. Limestone mines 
G.S. Esterhuizen, D.R. Dolinar, and A.T. Iannacchione ................................ 103

Keynote Address: Computerised control for robotically applied thin sprayed liniers providing technical, economic, environmental benefits as well as additional safety features 
I.W. Northcroft and C. Ziegler .................................................................. 119

Investigation of the characteristics of thin sprayed liniers (TSLs) and their use as an additional support medium in block cave mining 
J. Steyn, R.J. Gerber, and A.T. Harrison, and P.H. Ferreira .......................... 125

An effective face support system to minimise rockfalls 
N.D.L. Burger, A.J. von Wielligh, P.R. de Wet, R.W. Ottermann, and J.C. Visagie ............................................................... 145

Development of fast setting pumped foamed cement packs 
R.M. Smart and A.T. Harrison ............................................................... 159

Rock mass behaviour and support response in a longwall panel pre-driven recovery room 
S.C. Tadolini and T.M. Barczak ............................................................. 167

The control of coalmine roof collapse using cuttable foamed concrete support columns 
J.C. Visagie, J. Latilla, D. Neal, and C. Silver ........................................ 183

Static testing of shotcrete and membranes for mining applications 
E.C. Morton, A.G. Thompson, and E. Villaescusa .................................... 195

Smart materials technology for roofbolting application in the mining industry 
J.S. Moema, M.J. Papo, and R. Paton ..................................................... 213

A new rock bolt concept for underground excavations under high stress conditions 
F. Charette and M. Plouffe ................................................................. 225

The application of new generation support products in a typical sub-level block cave mining method to reduce safety risks and enhance productivity 
P.H. Ferreira, J. Steyn, and R.J. Gerber .................................................. 241

Filpak: Gully support in backfill stopes 
L. Dison and A.C. Smith ................................................................. 251

The use of voidfill barriers as an alternative to a grout pack support system in platinum mine conventional stoping 
A.E. Vidal da Silva .................................................................................. 267

Cempacks: Stope and gully supports 
L. Dison and A.C. Smith ................................................................. 289

The in situ performance of elongate support—myths and realities 
P.S. Piper and D.F. Malan ....................................................................... 299

Failure of transversely isotropic rock material: effect of layer orientation and material properties 
A. Tavallali and A. Vervoort ............................................................... 317

Numerical modelling of blocky and stratified hangingwall behaviour 
D.P. Roberts ................................................................. 329

Investigation into floor bearing strength of Indian coal measure strata by finite element modelling 
D. Kumar ................................................................. 345
<table>
<thead>
<tr>
<th>Title</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability distribution of rock properties: effect on the rock behaviour</td>
<td>357</td>
</tr>
<tr>
<td>B. Debecker, A. Tavallali, and A. Vervoort</td>
<td></td>
</tr>
<tr>
<td>Damage characterization of coal measure rocks under uniaxial compression</td>
<td>369</td>
</tr>
<tr>
<td>E. Kahlen and M. Alber</td>
<td></td>
</tr>
<tr>
<td>Effect of stress state on fracture initiation and growth around circular openings</td>
<td>381</td>
</tr>
<tr>
<td>A. Vervoort, P. Ganne, and B. van de Steen</td>
<td></td>
</tr>
<tr>
<td>Support coverage: An essential component in effective support design</td>
<td>391</td>
</tr>
<tr>
<td>J.S. Kuijpers</td>
<td></td>
</tr>
<tr>
<td>Rock engineering aspects of the Ingula Powerhouse caverns</td>
<td>409</td>
</tr>
<tr>
<td>G. Keyter</td>
<td></td>
</tr>
<tr>
<td>Grouting on the Kárahnjúkar hydroelectric project’s tunnels</td>
<td>447</td>
</tr>
<tr>
<td>N. Chittenden</td>
<td></td>
</tr>
<tr>
<td>Development of a corrosivity classification for cement grouted cable strand in underground hard rock mining excavations</td>
<td>461</td>
</tr>
<tr>
<td>E. Villaescusa, R. Hassell, and A.G. Thompson</td>
<td></td>
</tr>
<tr>
<td>Support system performance under different corrosion conditions</td>
<td>477</td>
</tr>
<tr>
<td>J. Hadjigeorgiou, J.F. Dorion, and E. Ghali</td>
<td></td>
</tr>
<tr>
<td>Effectiveness of support systems employed in the Finsch Mine Block 4 Cave</td>
<td>489</td>
</tr>
<tr>
<td>A.D. Wilson</td>
<td></td>
</tr>
<tr>
<td>Support challenges and experiences on Palabora block cave—initial mining through to full production</td>
<td>503</td>
</tr>
<tr>
<td>R.C. Jaggard</td>
<td></td>
</tr>
<tr>
<td>Development of a cement grouted rockbolting system for use in water-sensitive kimberlite</td>
<td>517</td>
</tr>
<tr>
<td>A.T. Harrison and D. O’Connor</td>
<td></td>
</tr>
<tr>
<td>Ground support at Crocodile River Mine located in the Brits Graben of the Western Limb of the Bushveld Complex</td>
<td>525</td>
</tr>
<tr>
<td>G. du T. Judeel and A.W. Hartmann</td>
<td></td>
</tr>
<tr>
<td>Ground support strategies to control large deformations in mining excavations</td>
<td>545</td>
</tr>
<tr>
<td>Y. Potvin and J. Hadjigeorgiou</td>
<td></td>
</tr>
<tr>
<td>Reinforcement support of concrete shaft lining in Westonaria formation lava in the Ezulwini vertical shaft system</td>
<td>561</td>
</tr>
<tr>
<td>W.D. Ortlepp, W.C. Joughin, A.K. Ward, and J. Thompson</td>
<td></td>
</tr>
<tr>
<td>Rock bolts testing under dynamic conditions at CANMET-MMSL</td>
<td>581</td>
</tr>
<tr>
<td>M. Plouffe, T. Anderson, and K. Judge</td>
<td></td>
</tr>
<tr>
<td>Dynamic testing of reinforcement systems</td>
<td>597</td>
</tr>
<tr>
<td>J.R. Player, A.G. Thompson, and E. Villaescusa</td>
<td></td>
</tr>
<tr>
<td>Support design using probabilistic keyblock methods</td>
<td>623</td>
</tr>
<tr>
<td>M.J. Dunn, P.J. Earl, and J. Watson</td>
<td></td>
</tr>
<tr>
<td>Ground support in Karstified conditions</td>
<td>637</td>
</tr>
<tr>
<td>J. Burke</td>
<td></td>
</tr>
<tr>
<td>The ongoing evolution of stope panel support at Impala Platinum Limited</td>
<td>651</td>
</tr>
<tr>
<td>I.J. Gardner and N.D. Fernandes</td>
<td></td>
</tr>
<tr>
<td>Optimum lead-lag distances in South African gold mines</td>
<td>665</td>
</tr>
<tr>
<td>O.D. Goldbach, T. Rangasamy, L.M. Linzer, M.O. Kataka, and S.M. Spottiswoode</td>
<td></td>
</tr>
<tr>
<td>Static and dynamic testing of steel wire mesh for mining applications of rock surface support</td>
<td>693</td>
</tr>
<tr>
<td>J.R. Player, E.C. Morton, A.G. Thompson, and E. Villaescusa</td>
<td></td>
</tr>
<tr>
<td>Review of face area support for Amandelbult No. 2 Shaft and subsequent introduction of cable anchors</td>
<td>707</td>
</tr>
<tr>
<td>L. van Aswegen and S. van Buuren</td>
<td></td>
</tr>
<tr>
<td>Autorock rigs for rockbolting in narrow reef stopes</td>
<td>721</td>
</tr>
<tr>
<td>F. Johnson and D. O’Connor</td>
<td></td>
</tr>
</tbody>
</table>